Science News

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BY

JOHN ENOGAT

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Editorial

It takes six months from the day it goes to the printers for each issue of *Science News* to reach the bookshops. With the best will in the world, we cannot at present cut the time any shorter. The result is that though we try to keep close on the heels of the laboratory workers, we always run the risk of being six months out of date. Science sometimes advances very rapidly indeed, and though the facts do not change, their bulk expands, and their interpretation is liable to any number of somersaults. Consequently, we can offer no guarantee of perfection in our reporting from the fronts of scientific knowledge. It is inevitable that the reports will sometimes be misleading, because scientists themselves were misled at the time the printer started work. All we can promise is that nothing appears in these pages until the research on which it is based has received reasonable confirmation and acceptance in the scientific world: this means that it is a part of current thought, and *not* that it is a final conclusion. More we cannot do, if we are to act as guide in the progress of scientific ideas and results.

Is Science a Closed Shop? The advent of the atom bomb as the result of years of team work in vast laboratories filled with complicated apparatus, and the trend of professional scientific research to use ever more elaborate machines—electron microscopes, refrigerated centrifuges, betatrons—and demand more and more technical training of its recruits, is in danger of convincing the layman and the amateur natural philosopher that it is. There seems no place any more for the enthusiastic schoolboy or schoolmaster, the man with a scientific hobby for the winter evenings, the amateur naturalist working on his own. Yet in fact the amateur and the lone worker still occupy a very important place, and this issue of *Science News* draws attention to some of the sciences where his contribution is valuable. Amateur astronomers have made many important discoveries in the past; radio has long proved a popular hobby; in "Detection of Meteors by Radar" Dr. Rabel shows how the two are now joining forces. Natural history is traditionally an amateur's field. In "Cave Science" Dr. Pavan reminds us of many problems waiting to be tackled at the bottom of pot-holes: speleology is almost entirely an amateur's science. Weather observation is another popular hobby: Dr. Kraus, though himself a professional meteorologist, writes of "Rain" in a way to interest the home observer. Anyone who reads Professor Aubrey Lewis's article on Mental Disease must be struck by the extent to which individual medical practitioners, often working on their own, have made important contributions to the subject. They possess that freedom to be bold which official bodies lack, but which the problem still requires. As a complete contrast—an approach to the workings of the brain through the study of single nerves, with the disciplines of physical science—we include Dr. Rushton's "How Nerves transmit messages". Finally we add our voice to the celebration of the hundredth birthday of the Chemical Society of London, with Dr. Sherwood Taylor's review of "A Century of British Chemistry".

Physical Treatment of Mental Illness

PROFESSOR AUBREY LEWIS

THE empirical methods of treatment introduced into psychiatry during the last 15 years had had the way prepared for them by Wagner Jauregg's great demonstration that general paralysis of the insane is not an inevitably lethal disease but one which can be arrested and, for practical purposes, often cured by malaria. The effect of this on the outlook of psychiatrists was so great, and the lessons of malarial treatment so relevant to appraisal of the later "shock" methods, that it is illuminating to consider very briefly how Wagner Jauregg's discovery came about and established itself. General paralysis of the insane had been a common diagnosis in mental hospitals, until the disease was recognised to be due to syphilis and laboratory tests were used to make the diagnosis more exact: then the number of cases was found to be smaller than had been thought. The disease was as fatal as cancer: an occasional patient might enjoy a long remission or drag out his life beyond the accustomed three or five years, but for almost all a series of downward changes leading to death in dementia could be predicted. Wagner Jauregg, however, took note of the old clinical observation that a long remission, or an apparent recovery, sometimes occurred in mental disease after a fever, and he decided in 1887 to turn this to account: the outcome was his use in 1917 of induced malaria. It was a bold experiment—to give malaria, itself a serious disease, to patients already doomed to suffer a debilitating syphilitic process: it could be justified only by the hopelessness of the disease and the impossibility of making the therapeutic experiment on animals: it was later justified also, of course, by its success. This success, however, was not immediately apparent, nor was it for some years generally acknowledged. The result of the treatment reported from various clinics differed enormously: the variations depended on the choice of cases to be treated, the skill and duration of the treatment, the period of subsequent observation, and the criteria used to assess improvement or recovery. Even now, in spite of many studies and hypotheses, it is uncertain how malaria brings about arrest and recession of the syphilitic brain disease.

Many of the features in this history have been repeated in the "shock" treatments of the last decade. But these treatments have been applied to forms of mental illness in which it is harder than it is with general paralysis to make a sure diagnosis, or to foretell the course of the disorder, if untreated, or to judge the degree and permanence of whatever change for the better the treatment effects. These illnesses are not associated with known pathological processes in the brain; their diagnosis cannot be much helped by laboratory tests; their course varies greatly from patient to patient, and can be favourably influenced by psychological and social treatment; there is room in them for wide difference of opinion as to the extent of a patient's improvement or recovery, since it depends, among other things, on an estimate of what he was like before he became mentally ill—if he had all his life been a man of lethargic temperament and careless habits, for example, a reversion to that state after treatment would have a different meaning from that which would be given it if it were the best outcome of treatment in a man who had before his illness been active and precise. All the difficulties therefore which attended the investigation and assessment of malarial treatment of general paralysis are present and enhanced in the treatment of schizophrenia,* affective psychoses, and other "functional" mental illnesses.

* See glossary under "psychiatry" for all special terms.

The three chief methods of physical treatment that have been introduced in the field—all between 1933 and 1936—make use of insulin, of induced convulsions, and incision of the frontal lobes of the brain. The insulin method was developed by Sakel in Vienna, the convulsions were first induced by Meduna in Budapest, and the frontal operation by Moniz in Lisbon. Modifications have come from workers all over the world.

Insulin

Sakel at first used insulin for overcoming the disagreeable symptoms that ensue in opium addicts when their drug is abruptly withdrawn. Although he used fairly small doses he occasionally produced severe symptoms of hypoglycæmia—reduction of the amount of sugar circulating in the blood—and the effect of this on the mental state led him to use it deliberately for allaying excitement, and (because of some speculations he made about the "vegetative centres" in the central nervous system) for treating schizophrenia. The essence of the method lay in the administration of a gradually increasing dose of insulin until the patient was passing each weekday into a deep unconsciousness or coma (with, sometimes, a convulsion) which was terminated after about an hour and a half by giving him sugar. Modifications have been mostly technical, and in the main the procedure now used is the same as Sakel introduced. The number of comas varies roughly between thirty and sixty, spread over several weeks; the patient concurrently engages in occupation and other helpful activities generally used as part of psychiatric treatment.

It was clear from the beginning that this treatment could not be administered safely by all and sundry: it needs a special unit, with nurses skilled to detect danger signals and doctors who know how to adjust the dose of insulin, assess the depth of the coma, and decide when and how to end it. In such hands the treatment is reasonably safe; the chief danger consists in a prolongation or return of unconsciousness in spite of the administration of sugar, and the more experienced the people in charge of the "insulin unit" the less frequent is the occurrence of this alarming complication, though even so it cannot be wholly prevented. The other serious risks, such as intercurrent affections of the lungs or heart, are rare in a well-conducted unit.

The treatment was instituted for schizophrenia, and schizophrenia has remained the condition for which it is judged appropriate: it has been tried in other mental illnesses with little or no benefit. Schizophrenia, however, is not—like general paralysis, or diabetes, or coronary thrombosis—a well-defined disease with unequivocal characteristics: the term is made to cover a wider range of illness in one country than in another, and may be used somewhat differently even by different doctors in the same country, some restricting it to a smaller core in which the symptoms are indubitable and mostly intractable, others applying it to a more heterogeneous collection of disturbances, having certain basic features in common but diverging widely in pattern and outcome. The future of the individual patient is in any case hard to trace with confidence: if he becomes well after insulin treatment it cannot be certain that this would not have happened with more routine methods of treatment. Consequently the results of treatment not only appear to differ widely in reports from the clinics in different countries, but they cannot be judged through study of individual patients, except where the patient has been ill so long that his recovery seems quite beyond hope—and such patients with long established schizophrenia are by common consent unresponsive to insulin treatment. The results of the treatment must therefore be assessed by statistical comparison of a sufficiently large group of insulin-treated patients with another group, untreated with insulin but chosen to match the insulin group in respect of all those factors which affect prognosis: both groups must be observed not merely at the end of treatment or as long as they are in hospital, but for two or more years afterwards to see how lasting is their improvement or their deterioration.

Such comparisons have been made. The fullest is that reported from New York State. The 1,128 patients of the insulin group had been treated in Brooklyn State Hospital, the control group (876 patients) in other mental hospitals in the State. Seventy-nine per cent. of the insulin group had been able to leave the mental hospital as against 58.8% of the control group. The insulin patients spent on the average 3.8 months less in hospital than the control patients. Among the patients who had to be readmitted to hospital, the insulin patients spent on the average two months more at home than in the hospital whereas the control patients spent 7½ months more in the hospital than at home. At the end of the period of study 59% of the insulin patients were at home, as against 44% of the "non-treated" group. Seventy-one per cent. of the insulin patients were earning their living, compared with 60.6% of the control patients. Such results seem to show a decided advantage in insulin treatment. They can, however, be criticised: the recovery rate is exceptionally high, and for some of the subgroups improbably so; the Brooklyn Hospital receives a higher proportion than other New York mental hospitals of the acute catatonic cases (which on the whole have a good outlook), and it discharges patients very early, with in consequence a higher relapse rate (42.5%) among the discharged insulin patients than among the discharged control patients (31.5%). But even allowing for these sources of possible error the New York figures make a strong case for the beneficial effect of insulin treatment.

The results of insulin treatment in the mental hospitals of Denmark were collected in 1941. Of the 276 schizophrenic patients treated 162 were classed as having indubitable schizophrenia, 114 were regarded as slightly dubious (though they would almost certainly have been classified as schizophrenic in any American or English statistics). Just over a quarter of the indubitable schizophrenics showed some improvement after insulin but half of these relapsed within a year; for the "dubious" schizophrenics the corresponding proportions were 50% improved, of whom approximately 40% relapsed. The authors of the report conclude "only very few cases of indubitable schizophrenia were cured but in a certain number of cases an improvement was obtained which justifies fully the continuation of this treatment. In non-typical cases of schizophrenia the results were considerably better; and the best results were obtained in psychogenic psychoses."

It is unnecessary to review further the rather discrepant reports, many of which are favourable. The bulk of reliable observers make the modest but confident claim that insulin treatment of schizophrenia effects better results than any other method, though it fails to benefit many patients, especially those with illness of long duration and ominous clinical features. Where observers compare the insulin results with those obtained by other standard treatment, the superiority of insulin is less evident (or is hardly evident at all) in those clinics which had a very high standard of therapeutic effort before "shock methods" came on the scene. It is true that enthusiasts for insulin treatment consider that in the clinics in question the new method was not carried out thoroughly enough to give its best results, but it is generally the case that those who worked in therapeutically active clinics are less impressed by the benefits of insulin than those who had previously taken an unduly pessimistic view of the outlook in schizophrenia and been disposed to think their diagnosis might have been wrong if the patient recovered.

The *modus operandi* of insulin was, in Sakel's original theory, upon the nerve cells and the hormones which, he believed, excited their activity especially in the "vegetative centres" (*i.e.*, parts of the brain controlling internal organs). His theory was elaborate and pretty well stillborn. Other explanations were put forward, most of them stressing the interference with brain tissue respiration entailed by the insulin, others pointing to the disturbance it causes in the autonomic nervous system, and a few insisting on a psychological explanation in terms of impending death and re-birth. One experimental study, made on rats, demonstrated that coma produced by insulin would restore previously inhibited conditioned reflexes, and this has been applied to what happens in human beings. It is, however, impossible at present to do more than describe some of the physico-chemical accompaniments of insulin treatment: knowledge of the relation these have to clinical improvement must await recognition of the essential bodily changes characteristic of schizophrenia.

Induced Convulsions

The treatment of mental illness by induced convulsions was based on the same sort of clinical observation as Wagner-Jauregg's introduction of malaria. Some patients with the catatonic variety of schizophrenia had become well promptly after they had a spontaneous convulsion; moreover, epileptic fits occur only rarely among schizophrenics (thus a Swiss investigator found only eight epileptics among 6,000 schizophrenics). A Hungarian psychiatrist, Nyiro, therefore tried the effect of transfusing the blood of epileptic patients into schizophrenics. The experiment was unsuccessful, but Meduna (following the same line of thought, which supposed that there must be some antagonism between the two diseases) decided to induce convulsions in schizophrenia. He made some experiments on animals which satisfied him that artificial convulsions do not cause serious damage to the central nervous system, and then by injecting camphor and later by intravenous injection of penta-methylene tetrazol, he carried out the human therapeutic experiment. The results were sufficient to encourage him to continue; after he had published his results, the method was quickly taken up all over the world. It had the advantage over insulin that it was easier to administer, not requiring such close medical and nursing attention, and the risk to life was slight. There were however other risks, presently to be mentioned.

Two major changes were effected in the treatment during the next five years: it was recognised to be less effective for schizophrenia than for melancholia, especially the melancholia of later life, and instead of drugs an electric current was used to produce the convulsions. The former clinical observation showed, as did more accurate statistics of incidence, that the theory of a supposed "biological antagonism" between epilepsy and schizophrenia had no substance, and that the introduction of this treatment had therefore been a lucky shot in the dark, at the wrong target. It was recalled that in the eighteenth and early nineteenth century camphor, in quantities sufficient to cause convulsions, had likewise been recommended for various forms of mental illness, but no systematic trial of the procedure had been made.

Other accidents or by-products of investigation led to the substitution of electrically induced convulsions for drug-made ones. As Delay says of this: *Il faut chercher pour trouver, mais non pour trouver ce qu'on cherche—c'est le paradoxe de maintes psychologies de la découverte.* A German neuro-pathologist, Spielmeyer, had called attention to the sclerosis (hardening due to excessive fibrous tissue) observed in a particular part of the brain of epileptics, and questioned whether it was a cause or consequence of the fits. Cerletti, an Italian neurologist and psychiatrist, decided to investigate the matter by inducing convulsions in dogs by the passage of an alternating current through the brain, and with his associate Bini succeeded in doing this without permanent damage to the animal. Further observations on pigs at the Rome abattoirs convinced Cerletti that it was safe to apply this method of inducing fits to human beings, as indeed some French and Swiss observers had shown in 1903-7. Meduna's method had certain obvious disadvantages—intravenous injection is sometimes mechanically difficult, especially after it has been carried out several times into the same vein; and, for a few moments before drug-produced convulsions, patients often experience a most distressing aura, the memory of which remains and makes them fear subsequent treatment. Electrical methods of inducing the convulsion avoided this, and are now almost invariably used, though there is some variation in the technical procedure, according to the instrument employed. Most psychiatrists have applied to the brain an alternating current of voltage between 50 and 150 volts, for a period ranging from a tenth to half a second.

The risks of the treatment are almost entirely due to the motor excitation. Thus dislocations or fractures may be caused by violent movements in the convulsion: chemical means can be employed to prevent such mishaps, but there are in turn some objections to the routine use of the drug (curare) appropriate for this purpose. Respiratory and circulatory complications can usually be foreseen and forestalled if there is thorough preliminary examination. Patients with pulmonary tuberculosis or a number of other systemic diseases may have their condition aggravated if given convulsions: but it is mostly a question of weighing the advantages against the risks in the given individual who has one of these diseases, rather than putting up an absolute bar against treatment by convulsions. Some observers, pointing to the severe damage to the brain in accidental electrocution, and to the impairment of memory which may follow the series of convulsions, have concluded that cell destruction must be reckoned as part of the price that may have to be paid for this treatment: but there is no conclusive evidence that there are permanent changes of any consequence in a previously healthy brain after a series of twelve or so convulsions.

The results of this treatment are reported in a large number of divergent papers, agreeing only about the dramatic recovery that may be seen in the middle-aged melancholic. The commonest view is that those mental disorders in which emotional disturbance is most prominent—termed the affective disorders—respond so well to convulsive treatment that it can almost be regarded as specific for them, especially for the "involutional" forms that occur in late middle life. At the other extreme are the small number of weighty critics and statistical watchdogs whose findings show that the recoveries produced in this way are not always maintained, and that the total effect is not appreciably different from that which can be obtained by thorough psychiatric treatment of the "non-shock" kind. It is possible to account for these discrepancies again by pointing to different choice of cases, different length and thoroughness of treatment, different criteria of success; and emphasis can be laid on the consensus of intermediate opinion, favourable to the treatment, as well as on the improvement or recovery sometimes effected in individuals when all other treatment seemed to have been futile, and the prospect was gloomily indicative of years of further illness. But the sober conclusion suggested by comprehensive studies like Dedichen's from Norway (in which 1,087 convulsion-treated patients whose subsequent history had been followed for a year and a half or more, were compared with 797 clinically similar patients treated without either convulsions or insulin) is that certainty about this treatment must wait on fuller knowledge of the pathology of the disorders treated and the *modus operandi* of the treatment, or on therapeutic experiments planned with as much care as if it were a question of crop yields to be studied at Rothamsted. Without the former knowledge the results of treatment in an individual case cannot be interpreted: without the latter designing of experiments needless variations and disputed claims leave the field dangerously open to "general impressions."

The *modus operandi* is still doubtful. The explanations offered are much the same as those for insulin treatment.

The most recent emphasises that induced convulsions cause excitation of the hypothalamus (a part of the midbrain) so that, through the connections of this part of the brain with the cortex, a state of heightened consciousness is produced where vigilance had previously been depressed by disease. This view of a French investigator is in keeping with the conclusion of others, that a disturbance of vegetative regulation is corrected by the treatment, for the hypothalamus is known to influence the functioning of bodily organs. But the evidence on which these physiological statements rest is incomplete; psychological explanations are also unconvincing.

The combination of insulin with convulsive treatment yields results which are in some cases better than can be obtained by either method alone, but it is not yet possible to predict which patients will respond to the combined treatment, nor does statistical examination of a group of patients treated in this way show it to have a general superiority over either insulin or convulsive treatment separately.

Leucotomy

An equally empirical but more radical procedure consists in making an incision across the white matter of the frontal regions of the two hemispheres of the brain. This was introduced by Egas Moniz in 1936 on the strength of some theoretical considerations about the anatomical basis of mental disorder and the function of the frontal lobes and their connections. His speculations on this went beyond what could be demonstrated, and are not generally accepted. The operation, however, proved reasonably safe, and beneficial to the agitated and excited patients on whom Moniz first practised it. It has since been employed on more than two thousand patients, chiefly in this country and the United States. It is not a lengthy operation, and can be carried out under local anæsthesia if the patient's mental state warrants this. It divides fibres connecting the anterior part of the frontal lobe with the dorsal median nucleus of the thalamus. The subsequent mental state of the patient may be like that of a person who has received a severe injury to the brain in an accident: he may become tactless, outspoken, careless, self-satisfied and without initiative. But these consequences are by no means always evident: in some patients even a skilled observer can detect little amiss once the immediate effects of the operation have passed off, whereas in other patients the subsequent condition amounts to a dementia; between these extremes many gradations may be seen, partly dependent on the previous personality and the illness of the patient in question, and partly on the location and extent of the cuts made through the frontal white matter. Psychological tests show that there is no impairment of formal intelligence as a rule: the subjects gain as high a score on standard intelligence tests as they had before the operation. In the practical affairs of life, however, many of them do not behave intelligently, and a number of psychologists have therefore tried to determine and measure the impairment in adaptive functions which this practical inefficiency connotes. It has been observed, for instance, that in the well-known Porteous Mazes those who have had a leucotomy (the name commonly given in this country to the operation) are at a disadvantage, since they do not look ahead. They do badly in other tests which are designed to measure capacity to hold back a motor impulse or persistence in attaining a goal one has set oneself. Study of the deficit produced by the operation is in its early stages, but has double importance: it will illuminate the way in which an interruption of fronto-thalamic nervous connections benefits certain forms of mental illness, and it will enable us to assess the price the patient pays for the benefit. The price may be a high one: apart from gross disturbances such as epilepsy (which are not unknown as effects of the operation) permanent blunting of the patient's sensitiveness and restraint may have to be reckoned with. On the other

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hand, these residual handicaps may be judged trifling, when set against the severe symptoms which the operation relieves. Obviously frontal leucotomy is not to be undertaken lightly, after a few months' trial of less drastic measures; the decision calls for a thorough appraisal of the social as well as the more narrowly medical issues in the individual case.

The patients who benefit most are those who are ceaseessly harried by painful ideas, or are given to outbreaks of uncontrollable violence. The more signs of emotional tension beforehand, the more gratifying the result. Whether the patient has a schizophrenia with persistent delusions and hallucinations, or an obsessional illness with persistent fears and impulses, the leucotomy, if effectual, will not usually abolish the morbid ideas but will make them bearable and unimportant to him: it is, in short, an operation to alleviate symptoms, rather than to end a disease. The symptoms may be of the kind that make it imperative for the patient to be nursed in a hospital, because of his outbursts of excitement: after the operation he may be no longer thus destructive and violent, so that he can return to his home or at any rate lead a quieter life in the hospital. In the recently collected findings of a thousand patients treated by leucotomy in this country, there were 364 recorded who had been violent before the operation; 260 of these were improved in this respect afterwards. There were, in this series, 757 patients whose illness had been going on for two years or more before the leucotomy: after it 173 of them were able to leave the mental hospital and were not known to have relapsed later. Of the 757, 489 were diagnosed "schizophrenia" and 150 "manic-depressive"; 15% of the former returned to live at home, and 38% of the latter.

Empirical Treatment

It is clear that these methods of treatment—insulin, convulsions, leucotomy—are not specific or, as yet, rational.

Like all empirical treatment that is not specific (in contrast, say, to the use of quinine in malaria) their development had to go through a hit-and-miss stage, the length of which depends on the care with which the therapeutic experiments are planned and conducted in order to disclose the range and mode of operation of the methods and the clinical indications for their use. And, like all methods of treatment in psychiatry that are not concerned with diseases having an established pathology and course (in contrast, say, to general paralysis) opinion as to their efficacy has to be judged in relation to a recovery which could have occurred without this intervention, either because the illness tended towards recovery anyhow or because other methods of treatment were being employed concurrently with benefit. It is impossible, of course, to deal with the patient as though he were a laboratory animal and to abstain from doing anything to help him except carry out the special physical treatment: if he cannot sleep, sedative measures must be employed; he will take part in the organised routine and occupations provided in the hospital; the doctor will see him and their conversations will inevitably have a therapeutic intention; and, indeed, the special treatment itself induces a temporary illness and dependence which demands nursing or medical attention to a degree that may have much psychological effect upon the patient. In a slightly older method of physical treatment—continuous narcosis (drug-induced sleep)—many psychiatrists believed that the virtues of the treatment actually resided in this induced helplessness which made the previously isolated and inaccessible patient receptive to psychological treatment.

It is generally conceded that in the main the patients who respond best to insulin or convulsions are those for whom the prognosis would have been good in any case: the newer methods of treatment shorten the illness, it is claimed, or prevent secondary products of the illness (*e.g.*, resentment at being a long while in hospital), but they do not, for the most part, turn a hopeless into a remediable condition. This obviously makes it harder to tell how much the special treatment has contributed to a recovery which could have occurred without it. Statistical comparison of sufficiently large and well-matched series of cases treated and not treated by the method is the proper recourse in such a difficulty: it has been employed by L. S. Penrose and many other investigators.

Insulin, convulsions and leucotomy do not exhaust the physical methods of treatment lately introduced into psychiatric practice. Continuous narcosis, brought into use in 1922, has already been referred to: it has its success in much the same kind of illness as convulsive treatment. Drugs such as amphetamine sulphate (benzedrine) and choline derivatives have been employed systematically. A "conditioning" method which makes use of a drug that causes vomiting has been effective with some addicts to alcohol. Nitrogen inhalations; faradic stimulation; "electrical narcosis"; artificially produced fever, sometimes combined with convulsions; and "refrigeration therapy" (in which the temperature of the body is reduced below 85°) have been tried, in accordance with some dubious theory or dubious observation, and for the most part have soon been dropped, as too dangerous or ineffectual.

Periodic Catatonia

The difference between empirical procedures and a rational psychiatric treatment may be seen on comparing them with Gjessing's work on periodic catatonia.* Gjessing, a Norwegian psychiatrist, began about twenty years ago a painstaking study of the metabolism of the very small group of patients in whom repeated attacks of catatonic stupor or excitement occur in a regular sequence: the condition is usually included in the larger class, schizophrenia, and is by some thought to be a blend of schizophrenic and manic-depressive illnesses. In a period of

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* See glossary under "psychiatry" for all technical terms.

13 years Gjessing investigated ten such cases over a total of 3,500 days. Having excluded all complicating influences such as chronic infections, he put his patients on a strict diet, and carried out daily biochemical examination of their blood, urine and fæces. He discovered that in place of the normal regular nitrogen excretion, periods of excessive excretion and excessive retention alternated, consistently related to the mental changes. In one type excitement or stupor sets in just after the time of maximum nitrogen retention, and lasts while over-excretion is going on to get rid of the accumulated nitrogen; in the other type the excitement or stupor sets in just before the time of maximum excretion and lasts for the greater part of the period of retention. A given patient will always exhibit the same type of relation. The assessment of the mental state and observation of its changes was made as objective as accurate records and the use of appropriate instruments could ensure. It seemed possible that the changes in nitrogen output might be dependent on excessive muscular activity (and under-nutrition) during the phase of excitement; but the second type of relation put this out of court, since the excitement there coincided with nitrogen retention. For this and other cogent reasons Gjessing concluded that the phasic disturbance of nitrogen metabolism constituted the fundamental pathology of the disorder, the mental changes being merely the outward symptoms. If, then, the metabolic anomalies could be prevented, the mental state would remain normal. The chief (though not the only) metabolic anomalies concerned nitrogen storage and excretion. Thyroxin is known to deplete the body's nitrogen store and thus increase excretion. Gjessing therefore gave a large dose of thyroxin (40–50 mgm) over 8–10 days to prevent any retention of nitrogen: a considerable loss of nitrogen and of body weight, occurred. He then gave maintenance doses of thyroid to keep the nitrogen store low. By this means, and insistence on a milk and vegetable diet with low protein content, the phasic changes in nitrogen output

came to an end. The patients he treated in this way remained free from mental symptoms for years.

Patients who have true periodic catatonia are few and far between, and the results obtained with them cannot be paralleled in other catatonic patients or in patients with other periodic mental illnesses. But the object lesson provided by this tiny group and the patient work of Gjessing on them needs no underlining.

A similar though less telling object lesson is afforded by tryparsamide, an arsenical drug, the product of extraordinarily careful systematic research, which is beneficial in trypanosomiasis and in general paralysis. Penicillin too is now being used for general paralysis. But Gjessing's work stands out since the condition he treated had been regarded not as a symptomatic psychosis, in which the mental features are manifestations of a known physical disease, but as a form of schizophrenia.

There are many who hold that psychoanalysis is likewise an object lesson in rational therapy. If the theory of psychoanalysis be accepted, then this contention must be upheld. There is however still, as everybody knows, much controversy about the correctness of the theory, and some uncertainty about the efficacy of the therapy. It is not necessary or appropriate to examine the views and evidence here; certainly psychoanalysis exercises a great influence upon psychiatric thought and practice. It is now more than fifty years since Freud and Breuer published their historic paper. Psychopathology and psychotherapy have developed during that half century in very intimate association; and if psychopathology rested on observations as easily made and verified as those of somatic pathology, there would now be little chance to wonder whether psychotherapy is rational or empirical. The same can be said of social methods of treatment which are now widely utilised, through the agency of the trained psychiatric social worker. Many methods have been brought forward of late years to widen the scope or intensify the action of social and psychological treatment: "group psychotherapy" is such a method which now occupies much attention. In all of them, however, it is plain that working out a technique of treatment, constantly modified in the light of individual or collective experience, is enforced by day-to-day clinical needs, to the detriment of therapeutic experiments planned with something of the same care as a laboratory investigation. This is almost unavoidable, as anyone may see who reflects on the complexity of psychological aberrations and their treatment, and knows what strong pressure to do something active and confident is brought to bear on the physician who undertakes such treatment.

This pressure of human need, always an important factor and the chief incentive in the development of therapeutics, has been responsible in psychiatry (as in other branches of medicine) for some wrong turnings and hasty expedients. In psychiatry, moreover, animal experiment can give little help as the preliminary testing-ground for remedies, since the main patterns of mental illness cannot be reproduced in other animals. For that vast part of mental illness which has as yet no known bodily basis, man alone can be the subject of crucial experiment; and although therapeutic experiments on man can be daring, as Wagner Jauregg and many others have shown, they cannot in a normal society be well controlled. Fuller said of the good physician that "he handsels not his new experiments on the bodies of his patients, letting loose mad receipts into the sick man's body, to try how well nature in him will fight against them, whilst himself stands by and sees the battle: except it be in desperate cases when death must be expelled by death." The good psychiatrist, though he recognises that the issues in mental illness are desperate enough, is averse from over-bold enterprises in treatment; but he is in the predicament, as other doctors have been too, that he must either wait until research throws more light on the causes and pathology of the diseases he treats, or he must try any new measures, from the outset, on volunteers who are aware broadly of the chances of improvement and the risks or uncertainties the treatment presents. This is in respect of new measures: for established treatment, the psychiatrist already has at his disposal a body of therapeutic experience and many procedures, both rational and empirical. The good results, though patently insufficient, bear comparison with what is attained in other branches of medicine.

Detection of Meteors by Radar

DR. G. RABEL

What is Radar?

FOR a long time past Radio Direction Finding has assisted in determining the position of a craft both in the air and on the sea. The aerial used for this purpose is a frame which can be made to rotate about a vertical axis. If the frame is set edge-on to the direction from which a signal is coming, the aerial gives maximal response. If it is turned round by 90 degrees so that the plane of the frame is perpendicular to the path of the signal, the response is zero. Thus the bearing of a signalling coastal station with respect to a ship can be ascertained, and if signals are taken from two or more radio beacons, the point on a map where these lines of bearing intersect gives the position of the ship.

R.D.F., then, requires the cooperation of some outside station—though, it is true, this cooperation may be entirely involuntary, as for example when an illicit transmitter reveals its presence.

The distinctive feature of Radar, or Radiolocation, is that it needs no cooperation whatever on the part of the object but works on its own, by sending out signals into space and watching the echoes which come back.

The fact that electromagnetic waves are of the same nature as light waves and can, like them, be reflected and refracted (bent) was demonstrated by Heinrich Hertz in 1888. When waves pass from one medium into another medium of different electric properties, *e.g.*, from air into water, one portion of the radiation is thrown back into the first medium, while another portion enters the second medium and becomes refracted. For instance a stick lying part in water and part in air looks as if it were broken, because the light rays from the under-water part are bent on crossing the surface into the air.

If the boundary surface is smooth, *i.e.*, contains no irregularities or ripples of the same order of magnitude as the wave length, the reflection is regular as from a mirror. If there are considerable irregularities, the incident rays are scattered in all directions as when light falls on frosted glass.

The time a wave takes to go out to an object and come back, depends evidently on the velocity with which it travels and the distance of the target. These three quantities are connected by the simple equation

$$\text{velocity} = \frac{\text{distance}}{\text{time}}, \text{ or distance} = \text{time} \times \text{velocity}.$$

The time for the round trip can only be measured if the moment of sending is precisely defined, that is if the transmission is interrupted. Fizeau was the first to introduce this method when he undertook to measure the velocity of light. He used a toothed wheel to provide periodical interruptions. To-day short "pulses" of a limited number of oscillations are sent out.

Fizeau knew the distance his rays had to traverse, hence by measuring the time they took he obtained their velocity. The radiolocator knows the velocity of his rays, hence by measuring the time he obtains the distance.

The Cathode Ray Oscillograph

As the velocity of radio waves in air is the same as that of light, namely 300,000 kilometres per second, a signal takes only 0.001 seconds or one millisecond to travel 300 km., and only 0.00001 seconds or ten microseconds to travel 3 km. No mechanical device could react quickly enough to make exact measurements of such time intervals, and wherever extremely quick response is required, the Cathode Ray Tube Oscillograph is put into action.

The main principle of this device, leaving out details, is this: an evacuated glass vessel in the form of a cone contains a pair of electrodes connected to a battery. The negative electrode, called the Cathode, which is placed at the narrow end of the tube, is heated by an auxiliary current so as to emit a considerable stream of negative electrons. These wander towards the positive electrode near by, called the Anode, and as the anode has a small hole in its centre, some of them move on through it and all through the length of the tube until they hit the broad end. This end is formed by a screen of fluorescent material and each time electrons hit that screen, a bright spot of light appears on it.

If somewhere between the anode and the screen two metal plates are fixed to the right and to the left of the tube, one of them charged to a positive, the other to a negative potential, the electron beam emerging from the cathode will be deflected towards the positive plate, and if the plates are alternately charged positively and negatively, the electron beam will follow suit and oscillate from the right to the left and back.

In practice, one of the plates is connected to a condenser which is periodically charged and then discharges itself quickly. Hence the electron beam sweeps horizontally across the screen and suddenly returns to the starting point. This movement of the electron beam is called "the Sweep" and the bright horizontal line it traces from left to right on the screen is called "the Time Base". The sweep is so adjusted as to work in time with the pulse transmitter. It starts at the utmost left corner each time a new pulse is sent out and moves over the screen with uniform speed. Therefore the distance of a point on the time base from its left end can serve as a time scale. If another electric field is applied perpendicularly to the first, that is above the tube and below it, it deflects the electron beam upward and downward.

In radiolocation, the incoming (reflected) radio waves supply the potential for the vertical electric field. But some grooming is needed before they can produce the desired effect. The waves are rectified, which means that their oscillatory electric force is transformed into direct current by the omission of one half cycle in each full wave. Then they are amplified because otherwise they would be too feeble. Thus prepared, it is they which deflect the electron beam away from the time base.

The times at which such deviations occur are easily measurable on the horizontal base, and as the travelling speed of electromagnetic waves is a known and constant factor, the scale can be graduated in kilometres (or miles) so that one glance on the scale provides direct, without further computation, the distance of the target. If the target moves, the bright pulse spot moves along the screen either towards the starting-point of the baseline or away from it. In modern equipment the azimuth of the object can also be read direct from a horizontal scale and the angle of elevation from a vertical one.

Only a few pulses are sent out in every second, because it is essential for the method that the energy from the reflected wave shall have died away before the next signal goes out. A station may send out, say 25 pulses per second, each lasting ten microseconds. That means that the whole span of time occupied by the signals is only 0.000250 seconds, or as the wireless man puts it: "the transmitter marks 250 microseconds". This very small "mark/space ratio" is characteristic for radar transmitters and explains the fact that very high pulse energies can be obtained. Suppose the peak power to be 800 kilowatt, the mean energy over a second would nevertheless only be

$$\frac{800 \times 250}{1000000} = 0.2 \text{ kilowatt or } 200 \text{ watt.}$$

When the attention of the wireless world was called to the fact that radio waves are reflected from layers of ionised gas in the upper atmosphere (the Ionosphere), scientists both here and in other countries set themselves to study these echoes systematically and soon they observed abnormal echoes of very short duration which seemed to come from passing meteors. A great number of these transient echoes were noticed during the Leonid shower of 1931, for instance.

Sir Edward Appleton suspected that passing meteors might be responsible for irregularities in the ionisation of the upper atmosphere, and therefore careful watch was kept over them.

However, it seems that the main interest aroused by this technique was at first directed to the practical implications of the phenomenon. Could not terrestrial objects, ships and aircraft, be detected by the same method? As early as 1931, the British Post Office made experiments on five metre wave length for this purpose and it was definitely established that a flying aeroplane, even if invisible, can be detected by a ground receiving apparatus.

In 1935-6 the first exploring station was installed at the east coast of England. Long before the war the system had been made foolproof for unskilled operators. The scientific exploration of the ionosphere together with the practice of direction finding has thus generated in this country the technique of radiolocation. The American term Radar was later adopted because it is shorter.

Meteors

Meteors (shooting stars) as a rule become visible at a height of 100 kilometres. As they enter the atmosphere with a terrific velocity, their impact upon the gas molecules of the air has two effects: heat and ionisation. A brilliant white light flashes up and columns of glowing ionised gas are left behind in the wake of the meteors, slanting down towards the earth. When they have reached a height of about 70 kilometres, the meteors are usually reduced to ashes, and vanish.

Most meteors are extremely small, like grains of sand, their radius being a fraction of a centimetre and their weight a few milligrams. A small percentage of them are larger; these manage to penetrate the atmosphere and to land on our earth. The well-known meteorites are exceptionally large ones.*

It is now often assumed that most meteors, if not all, are crumbs spilled when a comet hits on the atmosphere of our own or some other planet. An impressive example was supplied by the thrilling adventures of Biela's Comet. When this comet, whose period is 6¾ years, came near the earth in 1845, it consisted of two bodies which moved side by side slowly separating from each other. In 1852 they were farther apart. Neither in 1859 nor in 1866 was the comet sighted at all, but on the 27 November, 1872, it reappeared—this time transformed into a wonderful display of meteors. Since then the shower has repeated itself regularly, though with varying intensity.†

It looks as if roughly speaking meteor showers keep moving on the same track as their parental comet and that hence meteors, like the comets, belong to what has been called "the obedient family of the Sun", which revolves round the Master and follows him on his journeyings through the universe.

Meteors are known by two different names, a practice which is liable to confuse the layman. They have a family name derived from their real ancestor and a topographical name which designates their "radiant", the corner of the sky, the constellation, or to use for once astrological style, the "House" from which they seem to emerge. Thus the Bielid shower is identical with the Andromedids and the shower connected with the Giacobini-Zinner Comet which was observed in the autumn of 1946 is also named the Draconids.

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* Even the small percentage of larger meteors is said to amount to 146,000 millions a year and it is estimated that in 3000 years the mass of the earth has increased by 1 million tons thanks to these arrivals. However, even a million tons is a trifle as compared to the total mass of the earth.

† An amusing comment to this story is given by C. Olivier in his book on Comets. Professor Challis in Cambridge saw on and after January 15, 1852, two comets instead of one, but "he was troubled by many misgivings, having it evidently in his head that no well-behaved comet ought to divide into two. On the 24th he was finally convinced." He explained that he could not devote much time to a comet caught in the act of multiplication because he was busy searching for Neptune. "1846 was a year of hard luck for the professor. . . . He and Airy share the serious blame for losing for England the undisputed priority in the discovery of Neptune and here he lost another opportunity for making a unique observation."

It is rather surprising that a comet or shower whose period is anything between 3½ and several hundred years should, when it comes back, be met by us always at the same time of the year and coming out of the same house. We can only understand this phenomenon if we realise that the orbits of comets are very different from that of the earth, which is almost a circle. They are enormously elongated ellipses of which only a short piece lies in the neighbourhood of the sun while the rest stretches far out into space. A comet may come as near as five million miles to the sun (the nearest is 90,000 miles) and then escape very quickly and run as far away as 3,300 million miles. Such an orbit could almost be pictured as a very long pin with its head near the sun (perihelion) and its pointed end very far off. If a body travels along such a narrow orbit, it is plausible that when it comes back to the sun at all it comes back to the same house so that we encounter it at the same stage of our revolution round the sun.

Another at first sight paradoxical fact is this: if the period of a comet and its accompanying meteor throng is *n* years, how is it possible that we do not encounter members of this shower every *n* years only, but much oftener, in many cases actually every year? The answer is that as the shower goes on, it distributes itself evenly over the whole orbit and the longer a comet has sojourned in our solar system, the more uniformly scattered is its meteor stream. The Perseids, for example, or the Orionids, are met every year in about equal strength, whereas the Leonids, introduced into our solar system as late as 126 A.D. (when Tempel's Comet came into dangerous proximity to the planet Uranus) are not so evenly disseminated yet. On a bit of their track which takes three years to pass the earth they are closely packed and during these three of their 33 years' period they provide beautiful fireworks (unless another planet attracts them too much as happened in 1899); for the other thirty years, only a few of them are met annually.

We are now, at long last, prepared to come to the gist of this story and to speak of its hero, the Comet Giacobini-Zinner. A feeble shower from this comet was observed in 1926. In 1933, the earth passed the comet's orbit at a distance of 560,000 miles and the result was the finest meteor display of this century. It lasted 5½ hours and 400 meteors per minute were counted at the peak. In 1939, the distance was much smaller but the earth passed the node—that is the point where the orbits cross—4½ months before the comet did, and no meteors were seen.

In 1946, all circumstances promised to be exquisite. The earth was to reach the node only fifteen days after the comet and only 132,000 miles off from its orbit. No wonder that there were great expectations.

Meteors and Radar

This time it was not only astronomers but also radio experts who stood at attention to await the illustrious visitors. They had already gathered considerable knowledge about meteors on former occasions. They were aware that the radar sets used for the study of the ionosphere were not suited for astronomical observations and had prepared a special directional beam aerial; that means that instead of broadcasting indiscriminately into space, the aerial radiated energy only into a narrow channel and could be pointed in any direction.

Hey and Stewart had obtained hopeful results with radio echoes on January 3, 1946, when the Quadrantid shower, and on April 20-22, 1946, when the Lyrid shower was due. The echoes coincided to a certain extent with visual observation. Also when beams from different stations were directed towards the shower, and the directions established from which the echoes were strongest, plotting these directions on a chart revealed the radiant of the shower in good agreement with other computations.

This gave confidence that the echoes actually came from the meteors in question, but if radio echoes did no more than just confirm visual observations, they would not be the great triumph and promise for science they are.

In fact, thirty per cent of the echoes received appertained to so-called telescopic meteors which cannot be seen with the naked eye and are only detected if perchance they pass through the field of vision of a telescope.

Radio echoes do not come from the meteors themselves but from the lengthy filament of highly conducting gas which forms their trail or streak. The echoes are observed when the beam is directed at right angles to the length of the trail.

In one set of observations undertaken by Dr. Lovell and coworkers, about 1,000 echoes were analysed. The work was done on a frequency of 72 Mc (million cycles), per second, which corresponds to a wave length of 4.2 metre. The transmitter radiated 150 pulses per second, each lasting 0.000008 seconds. Peak power was 150 kilowatt. The activity of the Draconid shower was confined to a few hours on the 10th October from midnight till 6 a.m. The peak was reached at 3.40 with 168 echoes per minute; five minutes after the peak only fifty echoes per minute were left and at 6 a.m. the rate had decreased to 0.03 per minute which is normal in showerless times. The very rapid rise and decline impressed the observers and further they noticed a dissymmetry between ascent and decline which seemed to indicate that conditions before and after the peak were somehow different, though what really happened is not yet clear (see plates 17 and 18).

Most echoes were extremely transient, lasting hardly one half second. Visual observers were disappointed because both here and in America the weather was unfavourable—too many clouds and at the same time too much moon-light. By combining the results of several observers, however, a curve was obtained which showed, like the radio echoes, the very short duration of the whole shower and its rapid rise and decline. The maximum really observed was 16 meteors per minute, which, with some corrections, grew to 37.5.

But even the highest counts remained very far below those of 1933 when the conditions seemed so much less favourable. Meteors, if no longer a by-word for sheer caprice, are still not the most reliable inhabitants of this world.

J. S. Hey applied an ingenious method to measure the velocity of the meteors in a simpler and more accurate manner than astronomers could. There is a faint trace of an echo due to ionisation in the immediate proximity of the meteor. Then follows the main echo from the long ionised column. From the faint trace associated with the meteor itself as read off the time base the velocity could be computed and was, as an average from 22 cases, found to be 22.9 km. per second—in good agreement with other estimates.

Almost 23 kilometres per second is really a remarkable velocity. A meteor would travel from London to Cambridge in four seconds. If meteors at such speed meet the earth which itself speeds on at about 29 km.p.s., their velocities add up to more than 40 and the ionised trails produced by such impact are easily detectable. For the few meteors whose speed is greater than that of the earth, and which therefore are able to overtake it, the energy of impact is given by the difference between the two velocities which is small so that these meteors are not easily detectable.

But from now on astronomers will no longer be depending on what their eyes can see. They will neither be depending on good weather nor on the darkness of night for their work. When at a meeting of the Royal Astronomical Society Sir Edward Appleton inquired whether a maximum of meteor echoes at noon which he had found, corresponded to any astronomical reality, he was told: "On the distribution of daylight meteors the visual observer cannot say anything. We must leave it entirely to the radio observers to investigate these."

The astronomer Mr. Prentice said: "This beautiful new technique represents a major advance. We feel like the first possessors of a telescope, unexpectedly armed with new powers of observation."

By means of the narrow beam aerial array, the meteors of an individual stream can be studied in isolation, and a continuous record of the activity of a given shower can be maintained year by year, which was impossible hitherto. Further, the fact that meteors can be observed in daylight enables a search for new streams which can never be seen by the eye. Indeed, quite recently, in 1947, Lovell discovered the great Pisces-Aries-Taurus stream active from May to July, far wider and richer than any of the annual streams with which we are acquainted in the night sky.

When the European war was over, plenty of radar sets and radar teams in this country were unemployed; Sir Edward was asked to find work for them and he suggested they should detect sporadic meteors. So there exists now a huge and interesting collection of data taken round the clock for almost a year. The results are not yet available, but already Appleton and Naismith see their assumption confirmed that it is these sporadic meteors which keep up ionisation in the upper atmosphere during the night. We can hear night programmes on the radio, not only because the ionisation produced by the sun is retained but because the atmosphere is ceaselessly bombarded by the tiniest meteors.

Other Uses of Radar

Such a delicate detector of foreign bodies, *i.e.*, of objects with electric properties different from the air, cannot fail to detect plenty of other things apart from meteors, ships and aircraft. It seems that a complete picture of the landscape is offered to the flying pilot on some types of receiving arrays, if only in the form of spots and lines on the fluorescent screen.

When in 1943 high-powered transmitters were introduced, even birds did not escape detection, and bird echoes became such a menace for British coast watching that radar operators had to be specially trained to distinguish them from echoes of military importance. Aircraft can usually be easily distinguished by their greater speed; not so naval craft. At long range the echo from a bird flying fully in the beam of a radio set can be equal in strength and speed to that of a ship. In fact, birds have given rise to several E-boat scares and to at least one invasion alarm. Even small birds in flocks can be a nuisance to operators.

Heavy rain is also a reflector.

Cloud Range Detection

A special kind of Radar which uses extremely short electromagnetic waves, namely those of the visible spectrum, has recently been applied to measure the distance of clouds. A very intense light flash of one microsecond duration is produced by a high voltage spark gap at the focus of a paraboloidal reflector. The beam is aimed at clouds and the reflected flashes are received by another paraboloidal mirror with a photocell in its focus. The task of the photocell is to rectify the waves (let only one direction pass), then they are amplified and displayed on the Cathode Ray Screen as usual. The distance of the reflected spot from the time base origin measures the range of the cloud.

The Moon

Epoch-making has become quite a phrase in modern engineering. It cannot be denied that another epoch was opened when for the first time radar came in contact with the Moon. Assumptions that echoes might be obtained from the moon were never taken seriously until Sir Edward

Appleton categorically stated that it was possible. Less than a year later his prophecy was fulfilled by the United States Signal Corps. Wireless experts assert that the conditions were of the utmost unsuitability. The equipment was an ordinary and old-fashioned Army Signal apparatus of such size that it could not be lifted. Therefore the experiments had to be performed when the moon had just risen and was standing on the horizon. That meant that the atmosphere did its worst to attenuate the signals. But nothing of all this prevented a full success, and on January 10, 1946, at 11.58 a.m., contact with the moon was achieved.

An interesting peculiarity of the moon echoes is that they manifest the phenomenon known as Doppler Effect. When a source of vibration moves towards the observer, he receives more vibrations per second than the source emits, so that, for example, the pitch of an approaching engine is higher than when it is at rest. As the moon moved with a relative velocity of 682 miles p.h. towards the earth, the reflected wave differed from the transmitted one by 227 cycles. The American experimenters had calculated this effect beforehand and tuned their receiving set accordingly. The fact that this particular frequency was received, as well as the time lag of 2.4 seconds between transmission and reception, were definite proof that the echo really came from the moon.

Cave Science*

DR. MARIO PAVAN

THE study of caves in all their varied aspects is given the general name of spelæology.

Caves offer many different subjects of research to the student, and in the following pages we will glance briefly at their principal aspects, dwelling chiefly on the biological researches which have been the writer's particular concern.

No less worthy of consideration, however, is the explorative side of spelæology, which generally absorbs much energy and makes especial demands on the spelæologist. Indeed it requires a form of "Alpinism" whose chief characteristics are quite peculiar: it must be remembered that if the locality is new, a genuine *exploration* has to be made with all the unknown quantities and surprises inherent in unexplored territory, and with the disadvantage of being nearly always cut off from any kind of communication with the outside world. But if this were all it involved it would still be a relatively simple affair.

The exploration proper is only started after a long series of preliminaries ranging from locating the exact site of the cave to transporting the necessary equipment and making all the preparations. Lined up together on the ground for hunting and collecting are strange-looking bandoliers made like cartridge belts but provided with thick glass test-tubes, and in some cases, pairs of peculiar steel pincers or leather harness with hooks and strong rings; small cases containing compasses, goniometers, altimeters, thermometers, barometers, and hygrometers; helmets with odd-looking lamps and flexible tubing fixed on top, coils of rope, ladders of flexible steel cable, miners' lamps, accumulators for under-water lighting, overalls, floats, diving suits, field telephones, and other objects which are of less bulk but just as necessary and precious as the others. Then, if we are dealing with chasms, begins the longest, most fatiguing and most delicate of all the preparations, the one on which the outcome of the exploration largely depends—the putting together of the equipment used in descending the abysses. The actual exploration often presents extreme difficulties; climbing down overhanging walls, wading through rivers or basins of ice-cold water, negotiating cascades or under-water 'siphons' or large semi-liquid deposits of bat guano, in which there is a risk of sinking and being swallowed up as in quick-sands.

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*Translated by Teresa Magnani.

All this often necessitates spending long periods underground, which may stretch into days on end, often in danger of an unexpected storm bringing down enormous torrents of water from which escape is difficult. On August 25th, 1925, this misfortune actually befell the unlucky expedition which was exploring the Bertarelli Abyss, when two men were swept away and dashed to pieces by the force of an unexpected flood, while the rest of the party escaped only with great difficulty after indescribable adventures.

Even greater complications and perils are encountered when exploring caves with vertical shafts, especially when these are the site of water phenomena.

Since lively interest has always been aroused by the great depth of some of the caves, a table is given below of the principal caves of the world arranged in order of depth. (Multiply by 3¼ times to convert metres to feet).

Cave	Depth	Locality
Spluga della Preta (Chasm of the Preta)	637 m.	Venetia, Italy.
Antro di Corchia	559 m.	Tuscany, Italy.
*Fledermaushöle (The Bat Cave)	557 m.	Styria, Austria.
Anou Boussouil	520 m.	Djurjura, Algeria.
Abisso di Verco	518 m.	Venezia Giulia, Italy.
Abisso di Montenero	500 m.	Venezia Giulia, Italy.

*not completely explored

Cave	Depth	Locality
Abisso Bertarelli	450 m.	Venezia Giulia, Italy.
*Henne Morte	446 m.	Haute Garonne, France.
Abisso Frederic Prez	420 m.	Venezia Giulia, Italy.
Grotta Gugliemo	350 m.	Lombardy, Italy.
Pozzo di Trebiciano	329 m.	Venezia Giulia, Italy.
Tana dell' Uomo selvatico (The Wild Man's Den)	318 m.	Tuscany, Italy.
Il primo abisso del Colle Schirlenico	316 m.	Venezia Giulia, Italy.
Abisso Revel	316 m.	Tuscany, Italy.
Sarkotich	310 m.	Montenegro, Yugoslavia.
Grotta dei serpenti (The Serpents' Cave)	304 m.	Venezia Giulia, Italy.
Abime Martel	303 m.	Ariège, France.
Inghiottoio di Slivia (Gulf of Slivia)	303 m.	Venezia Giulia, Italy.

In France they have recently explored the Chevalier Cave (Dent de Crolles, between Grenoble and Chambéry) which has its own peculiar morphology, formed systematically so to speak by a tunnel with two mouths on opposite slopes of a mountain and with a series of wells rising vertically from the middle of the cave to the summit of the mountain. The distance from the outer mouth of the well to the lowest mouth of the tunnel is 658 metres.

Primitive human and animal life in the caves

Spelæology is indeed young; it has approached full status and taken its place as a serious science only in the final decades of the last century, mainly owing to the work of the Frenchman E. A. Martel. From its first beginnings it has owed a great deal to many other branches of science, and throughout its development has always maintained far-reaching and intimate connections with the other sciences.

A generalised interest in caves had already been aroused in the rare observer as far back as the Middle Ages, but we have few accounts of their explorations which are worthy of record, apart from awe-struck reports of the inevitable "stone-forest" or the immensity of the subterranean regions.

*not completely explored

A particular interest was awakened in their minds by the mysterious origin of underground caverns, and among a variety of extraordinary hypotheses put forward on the subject were some reasoned views ascribing that origin to the erosive action of water. The underground circulation of water continued to be a favourite topic right up to the nineteenth century: during this period the hydrology of the caves was considered to be the largest and most important problem raised by spelæology: and it is not out of the question that from a practical point of view this may indeed be one of the fields in which the study of the world underground will yield the greatest results.

In the course of these early investigations, layers of fossilised bones were discovered, which were considered tangible evidence of the much discussed destruction wrought by the hypothetical Flood.

The discovery some time later of the remains of human occupation revealed the customs and habits of a people who had taken refuge in these regions tens of thousands of years ago. All the articles of those distant times, fashioned in the hardest types of stone (flint, crystalline rock, etc.), came to light a few at a time, and along with them were found not only the bones of animals now vanished from these regions, or even completely extinct, but also the remains, though of course also fossilised, of our remote ancestors.

Such finds aroused at first—and it was not many years ago—an unusual degree of interest, since they were held to belong to the famous, though according to present opinion fictitious, man-ape, the connecting link between us and the animals which became the subject of lively polemics between the supporters of this theory and those students who rightly opposed it. The palæanthropologists went on with their researches in this field in the hope of one day discovering the hypothetical "Tertiary man"; although this result has not yet been achieved, the discoveries which follow from year to year are both important and encouraging.

The spelæologists can certainly be given credit for discovering most important traces of the art of primitive man—marvellously preserved after tens of thousands of years—in caves in various parts of the world and, especially in Europe in the Pyrenees. For example, there is the statuette of a bison found by M. Begouen in the Tuc d'Audobert cave, and the headless statue of a cave bear, whose origin is attributed to an era twenty thousand years ago, which was discovered in 1923 in the Montespan cave, thanks to the efforts of N. Casteret.

These surprising and sensational discoveries aroused enormous interest all over the world, for they were destined to shed new light on the much-debated problems of primitive mankind.

Parallel with these celebrated studies there has in the last few decades been a remarkable expansion in all the other scientific or practical fields of research, especially in palæontology. Systematic excavation has brought to light vast layers of fossilised bones of animals now vanished from the face of the earth, making possible a better knowledge of the fauna and flora of geological periods remote from humanity, and showing up clearly the different climatic phases which followed one another on each continent and which determined the successive different types of fauna and flora, of which clear traces remain in the caves.

It seems to-day almost impossible that the European continent should once have been overrun by elephants, or mammoths, by gigantic cave-bears, or by lions and tigers, but the fossils found in the caves bear certain witness to it. In some caves in the Pyrenees they have found traces of claws and fur left in the clay by *Ursus spelæus*, while in other caves it has even been proved that the rock walls in very narrow passages have been rubbed smooth by the friction of the bears' fur as, perhaps for thousands of years in succession, they pushed their way into the caverns where they had their lairs.

The palæontological deposits found in caves are of remarkable thickness—sometimes many feet—and often very rich in precious fossil substances. In the cave called Bucco dell' Orso (The Bear's Mouth) on Lake Como in Italy, for example, it has been calculated that there are at least three hundred skeletons of cave-bears !

The practical importance of subterranean hydrology

The importance of geological researches carried out in the caves is immediately obvious if we consider that one of the endeavours of the geologist is to compile maps of the earth's depths, proceeding by examination of the surface evidence.

The help which can be derived from direct investigation into the heart of the rock is, however, limited by the fact that the existence of caves is not a universal phenomenon but appears only in certain territories containing soluble rock (calcium carbonate). Caves in other regions are due to different causes possibly having nothing to do with the dissolution of calcareous rock under the action of water. They are rare and of negligible importance.

The geologist can, in any case, study all the problems inherent in the origin, development, and destiny of subterranean caverns; valuable discoveries can often be made of the circulation of underground water, with particular regard to its practical utilisation for hydroelectric power, irrigation, and the supply of water for the needs of man.

In connection with the supply of drinking water to the city of Trieste a lengthy investigation was made into the subterranean hydrology of the Carso, which was summarised in masterly fashion by E. Boegan in "The Timavo", a work published in the collection of "Memoranda of the Italian Institute of Spelæology (Postumia)". As a result the aqueduct serving Trieste uses water from the Randaccio spring, which is fed from the subterranean course of the Timavo—the largest and most typical underground river in Europe.

It is a widespread belief that underground water is free from impurities detrimental to the health of man, but although we may drink such water quite freely when it is distributed by modern aqueducts furnished with perfect sterilisation plants, there can be no such guarantee of safety when the water reaches us without undergoing the special purifying process. In actual fact water circulates through the strata of calcareous rock by means of cracks which are large enough to allow the passage of dangerous organic impurities along with the liquid. It is very rare for water flowing underground through the fissures in calcareous rock to be free from dangerous infection. Moreover people living on the mountains frequently get rid of the carcasses of animals which have died of sickness, and of offal and domestic refuse by tipping it all into the caves. The water infiltrating into the ground then soaks up these deposits of decaying matter and carries their poisons and disease-laden bacteria to the distant spring, which is not suspected of being anything but pure and wholesome. The annals of hygiene record numerous cases of epidemics and of wholesale and persistent poisoning whose origin has been traced to the deplorable practices described above. Sanitary legislation has therefore intervened in many countries and forbidden the throwing of any kind of rubbish whatever into the caves.

The Trou du Toro (Hole of the Bull) is a great gully 2,000 metres above sea-level in Spanish territory in the Maledetta massif of the Pyrenees, not far from the French frontier. The waters of the Rio Barranco are swallowed up and engulfed within it. The Spaniards had intended to divert the waters of this torrent before they disappear into the Trou du Toro, but there were some who suspected that the water spread underground and went to feed the Garonne in French territory, so that its diversion within Spanish territory might irremediably weaken the flow of the French river, with grave consequences for the farming population.

In 1938, after courageous and patient investigation, the French spelæologist N. Casteret succeeded in demonstrating scientifically the correctness of this thesis, and the international issue it raised was settled in favour of France, which, thanks to this expert student of caves, was able to safeguard the interests of the vast area irrigated by the Garonne.

In recent years the caves have been the site of important work in geodesy carried out with delicate and expensive scientific instruments, and a parallel study has been made of the singular meteorology of subterranean caverns, often with strange and unexpected results.

As cosmic radiation is studied in all the layers of the atmosphere, in the depths of the sea, and of fresh water, so too this study has very properly gone underground in order to find out the penetrative powers of these mysterious rays through different types of rock and under varying conditions. This kind of research will not of course remain isolated, but interesting possibilities are bound to develop of transferring its results from a purely theoretical field and applying them to the study of subterranean biology and to mining conditions.

Nor should we forget the important place taken by caves in the history of warfare, and above all the military and civil function they might assume in atomic warfare.

The United States are therefore carefully investigating the complex possibilities of the vast collection of galleries in the Mammoth Cave in Kentucky, an enormous natural cavern covering several miles.

Biospelæology: the study of cave vegetation

After this brief summary of some of the principal fields of study and possibilities of practical application in spelæology, we will pay somewhat closer attention to its biological aspect.

The flora of the caves has aroused scant interest in botanists, but they would in fact repay the most thorough study, since there are many particular aspects worthy of investigation.

The higher plants are only found in the areas near the cave-mouth and those parts of the cave lighted either directly or by reflection from outside, which do not offer conditions of life differing excessively from the normal, and therefore give rise to no outstanding phenomena.

In the interior of the caves, where there is no light at all, the synthesis of the leaf-green pigment chlorophyll cannot occur, and in consequence the flora consists entirely of saprophytes which live on decaying organic matter, instead of relying on photosynthesis.

The fungi frequently found in caves, upon the usually plentiful organic vegetable or animal remains, often exhibit obvious cryptomorphic phenomena, *i.e.*, alterations in their usual structure which make it impossible to recognise the species to which they belong, for in the majority the reproductive organs rarely reach maturity, and so there can be no examination of the seeds, the usual determining factor in the identification of the different species. In some caves which have been adapted for tourists, and have electric light installed (which is turned on at intervals), species of the higher plants have succeeded—though with difficulty—in developing near these sources of intermittent light, making use of the little that they provide for photosynthesis. As an instance we may mention the existence of a new variety of moss (*Brachytegium velutinum* var. *spelæorum* Latzel) which developed near the "Grande Monte Calvario" in the Postumia Cave 1,700 metres from the entrance. This new moss formed a group with other vegetation in proximity to a 500 watt lamp which was turned on for about 500 hours a year (see plate 26).

In recent years attention has been drawn to the common phenomenon of the blackening of concretions in the Postumia Cave, and examination of the blackened patina has revealed the presence of micro-organisms in various stages of development.

I. Politi, who performed the preliminary work, suggests that the bacterial flora present on the concretions may be at least partly responsible for the blackening of the surface, since one suspects the presence of micro-organisms which take up iron oxide and manganese oxide, salts with the characteristic brown or black colour of the discoloration. The blackening of the walls of caves is often, however, due to different, non-biological causes, such as deposits from the dust-laden atmosphere, or particles of carbon from the combustion of the lights used by visitors, or from the fires of cave-dwellers in remote times. Apparently identical phenomena do not always spring from the same cause.

After this note on the study of vegetable biology we will look at some details of animal biology.

The fauna of the caves

If little work has been done on the flora of the caves the same cannot be said of the fauna, which has aroused and continues to arouse a most lively interest.

The first documentary evidence of cave fauna proper comes straight out of the prehistoric Magdalenian epoch, for it is an incising on a fragment of a bison's bone found in the "Trois Frères" cave at Ariège in the French Pyrenees.

The incision represents a cavernicolous insect (*Troglophilus*) which has now disappeared from the Pyrenees and from the whole of Western Europe, but which still exists in regions further East (Italy, the Balkans, Asia Minor). The unknown artist has transmitted in this fragment the most ancient evidence we possess of real cave fauna, which is attributed to an age many thousands of years past (Plate 28).

Prehistoric sculpture and drawings representing other animals (bears, lions, mammoths etc.) which go back to an epoch even more remote than that of the *Troglophilus* incising, do not possess the significance attributed to the latter, since though these animals were presumably the guests, even regular ones, of the caves, they were not properly at home in the subterranean regions.

Next we make a jump to G. B. Trissino who, in the first half of the sixteenth century, saw in the Covolo di Costozza in the Veneto, some little fresh-water crustaceans (*Niphargus*), referred to briefly by F. Leandro Alberti in his "Description of the whole of Italy" (see Fig. 1).

No really significant event occurred, however, until 1768 when the first description appeared of the "Proteus", that extraordinary amphibious newt belonging to the Cave of Istria, which became the most celebrated cavernicolous animal (see Plate 29).

In the last century the general flowering of science gave a notable impulse also to research on animal life in caves, which, it came to be realised, raised biological problems which were both new and highly interesting even from a general point of view. But while the few spelæologists concerned themselves with the new problems presented by the animal population of the caves, the biological aspect was somewhat neglected in favour of the systematic study of zoology. This played the most important part for a long time, which is understandable when it is considered that the caves, even in our own regions, were—and in part still are—virgin territory full of the most alluring new things. To cite only one example from one of the regions most studied by spelæologists—the province of Brescia in Northern Italy—in the past twenty years of biological research we have found at least fifty genera and species hitherto unknown to science !

At the beginning of this century, Racovitza made a survey of biospelæology and drew up a research programme based on the subjects which seemed to him the most important ones to investigate. His work aroused the attention of cave explorers and was a spur to the widening of our knowledge of the life of cavernicolous fauna.

When considering animals in relation to their cave environment, it should immediately be made clear that not all those found in caves are inseparable from them. For many years animals were in fact grouped in three categories

—those which lost their power of reproduction in a cave environment (troglosseni), those which retained this power and could still live in daylight (troglophili), and those which were compelled to spend their whole existence underground, from birth to death, and could not survive in daylight (troglobi). In 1944, the writer extended the scope of this division by pointing out that the troglosseni only arrive in caves by accident, whereas the troglophili actively seek out and prefer the underground dark.

Opinion is divided on the origin of the third group, the compulsory cave-dwellers. Some hold that in very remote times there was no proper cave fauna; that following the setting in of external climatic conditions unsuitable to many forms of animal life, these took refuge in the caves; and after a long period spent in their new surroundings they became completely dependent on the conditions of life underground and incapable of returning to the outside world.

Others suppose that through an actual organic tendency in certain animals these were to some extent forced to seek living conditions which only exist underground, and that the origin of the ties which they have contracted with the caves existed prior to their migration into that world.

One of the various other hypotheses finds the origin of the true troglobi in animals which came into the caves by chance and slowly settled in these surroundings, giving rise to all the troglobian fauna that we now know.

It is obvious that none of these hypotheses can be accepted or rejected in its entirety. Each one of them may correspond to some actual case, but none of them can be accepted outright as having a general validity.

When the distribution of cave animals is studied in further detail, it is found that underground water, like the land, shelters well-defined groups of animals. Even round the mouths of caves, there is a characteristic animal population made up of organisms which love damp, and seem to seek out this environment because the humidity varies less than does that of the normal open world. Occasional caves which are excessively dry, or subject to passing seasons of dryness, often possess a fauna few in numbers and variety.

Light is not a decisive factor in determining the population of a cave. Many other considerations are of much greater importance: temperature, presence and degree of decomposition of vegetable and animal remains, constancy or renewal of the atmosphere, and the physical structure and chemical composition of the ground itself.

Some of the troglobi which love a high humidity can pass indifferently from land to water and back again. The writer has repeatedly seen this in different species of arthropods in caves in Northern Italy; for example Machilia, Trichoniscus, and an unidentified millipede. Sometimes, too, aquatic animals are found out of the water, for example a flat-worm (planarian), and an amphipod crustacean called Niphargus. This latter animal is often found in the waters of European caves, but where the cave is dry it digs out a little hole in clay with a tiny tunnel

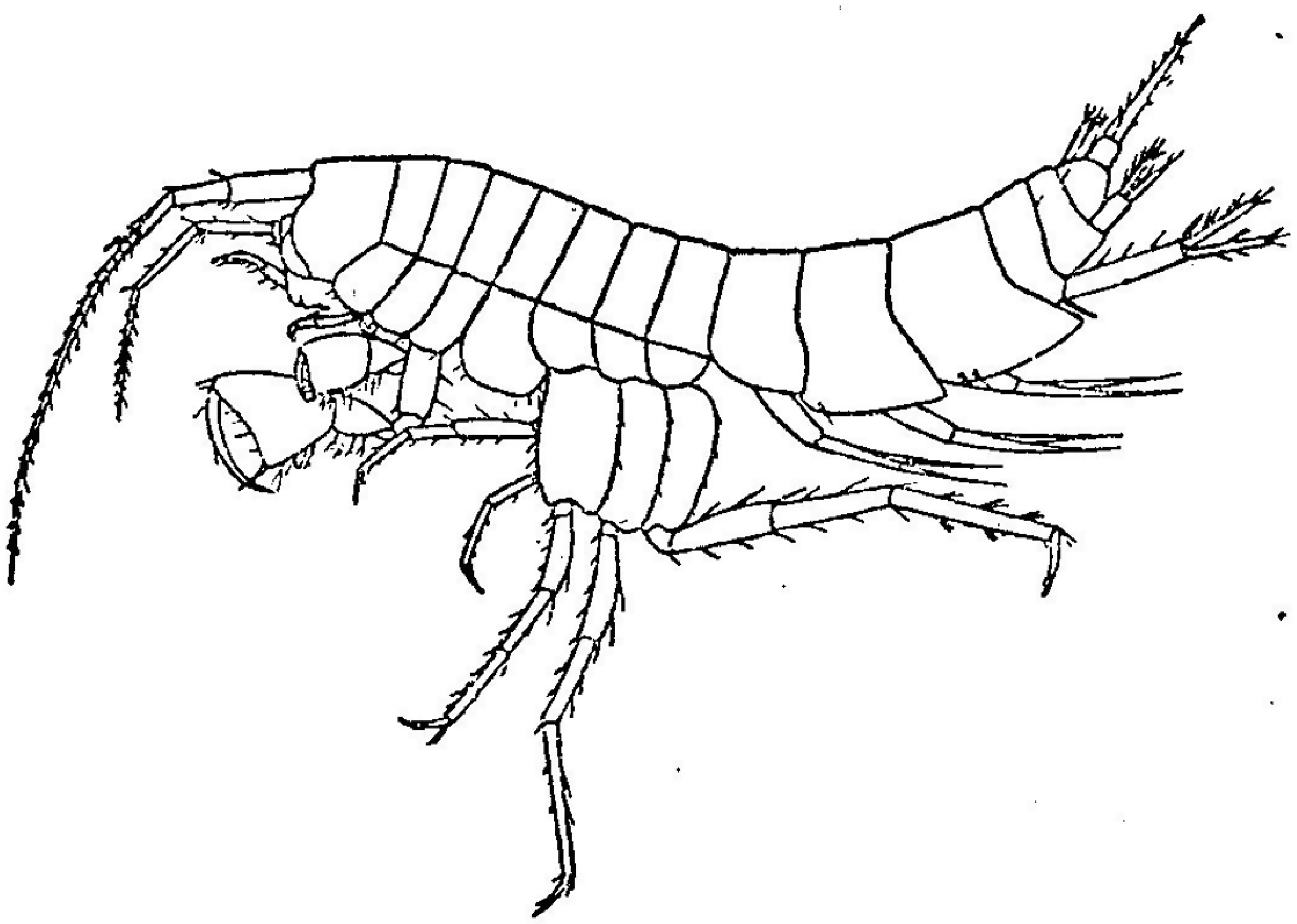

Figure 1

running vertically to the surface. This shaft collects the minutest droplets of infiltrating water, and so keeps the Niphargus moist, however dry the cave as a whole may be. If its cell is opened inside the dry clay, a drop of water is often found. Facts of this sort suggest that given a saturated atmosphere, some cave animals do not distinguish clearly between air and water, and their respiratory processes must function equally well in both environments.

A problem of this kind is perhaps best studied in the laboratory in large experimental chambers in which the conditions of temperature, moisture, etc., can be controlled at will; or at the special underground laboratory fitted out fifteen years ago in the wonderful cave of Postumia in the province of Trieste. Unfortunately this laboratory was damaged by the German Army during the 1939-45 war, and it has recently come under Yugoslav administration; political unrest in the Trieste region makes its future uncertain.

This brief survey has touched on only a few of the problems of spelæology, but it has been enough to indicate that the subject has a definite contribution to make to geology, archæology and pre-history, and in biology to the problems of Evolution and adaptation.

Physics Front

A. W. HASLETT

Atom Postscript

A NUMBER of additions can now be made to the survey of atomic energy given in *Science News II.* One is the fact that thorium can be "transmuted" in an atomic pile into a new form of uranium—U.233—which like U.235 and plutonium is capable of being used as a "nuclear fuel". This is of importance, as well as interest, because there is rather more thorium in the world than uranium; and both India and Brazil, the two countries which are richest in supplies, are eminently capable of further development. There is, however, one very practical distinction between the utilisation of thorium and that of uranium as a source of atomic energy. It is that, whereas processes based on uranium are self-contained, processes based on thorium need small quantities of either plutonium or U.235 to start them off. And these are the only two materials from which atom bombs have so far been made.

A further point of interest about U.233—the new form of uranium—is that it is the starting point of a new radioactive series, which includes a hitherto unknown form of radium. The three existing series are those commonly associated with radium, actinium and thorium respectively. The starting points of the first two series are U.235 and U.238—the two commonest of the naturally occurring forms of uranium. Between them, these three series of radioactive elements include the whole of the known natural sources of radioactivity. They were laboriously worked out by Lord Rutherford and Professor Soddy in Canada early in the present century, and provided the foundation on which all modern knowledge of the atom was built up. It is therefore of rather special interest, scientifically, that a fourth series should have been discovered, which is comparable in all respects with the other three, except that the radio-element from which it starts is not found in nature.

A natural first thought would be that the new form of radium which is included in this series should be of use in medicine. This is not, unfortunately, the case. It is neither long enough lived to be of practical use, nor is the radiation which it produces comparable with that from natural radium. This gap has, however, been filled by another discovery which also has only lately been published. It has been found that a radioactive form of cobalt can be made, merely by exposing normal cobalt to the intense neutron bombardment provided in an atomic pile; and this cobalt produces radiation which is very similar in quality to that of radium itself. It is, in fact, of somewhat more uniform character and medically, therefore, will probably prove more satisfactory to work with. Moreover, it can be made in quantities which could be large, compared with those in which radium is normally used; and, although it lacks the "permanence" of radium, rather more than four years has to go by before the strength of its radioactivity falls off by half.

The Photographic Plate in Research

Although attention tends inevitably to be focussed on the release of atomic energy and its consequences, nuclear physicists are more interested—aside from the social and international aspects—in fundamental research. Here, the main problems to be investigated are two. The first is to discover the nature of the forces which hold the nucleus of an atom together. This may seem curious when it has already been demonstrated that atoms can be induced to come part—and that on a wholly practical scale. None the less, it is true that, although there are ideas in plenty, these have not as yet been translated into any systematic and certain body of knowledge—or even into a single theory which makes sense. The second need, which ties up with the first, is for more knowledge about the fundamental particles, already known or predicted in physical research.

For both these purposes, two main lines of research are available. One consists in the design and building of equipment in which particles can be accelerated to higher and still higher energies. This might be described as the bombardment approach. Its plans are measured in hundreds of thousands of pounds, and in millions of dollars—and, from the nature of the case, will take time to mature. The other main line of research is one in which relatively rapid progress is already being made. It is virtually without cost, and consists in the use of special photographic plates as so many miniature laboratories in which nuclear changes can be studied.

It is easiest to begin by assuming the result. Let us suppose that, for reasons unknown, the nucleus of an atom "explodes" at a point inside the sensitive layer of a photographic plate. As with any other explosion, a number of fragments will be produced which will fly apart, in different direction, and at different speeds. Being atomic particles, however, they will in most cases be electrically charged; and, as such, they will affect the photographic plate in the same way as would exposure to light. In other words, when the plate has been developed the tracks of particles will be found to have been recorded in it (see Plate 31).

As a research method, this was first systematically developed by Dr. C. F. Powell of the University of Bristol. It is less easy than it sounds, because the emulsion of the plate shrinks during developing and fixing—thus distorting the tracks—and the tracks are in any case distributed in three dimensions. None the less, Dr. Powell was able, over a period of years, to work out methods for recording accurately the lengths and directions of the original tracks, and for distinguishing between the different possible kinds of particles.

The principal new development has been the introduction of special plates, in which the number of sensitive grains is greatly increased, and with the aid of these plates there has been a sudden outburst of research, using the methods which Dr. Powell earlier developed. The particular value of the method is that, pending the completion of the high-energy laboratory equipment already mentioned, cosmic radiation from outer space offers the only available source of particles of the highest energies for bombardment. Such particles are, however, comparatively few and far between, even at high altitudes in the earth's atmosphere—for example at a mountain-top laboratory, or during an aircraft flight. And the special advantage of the photographic plate is that it will record automatically all transmutations which may be produced within it during the period for which it is exposed. During the past six months, this has proved the most useful of all available research methods, and the same will probably remain true also during the next year.

Thirty Million Volt X-Rays

Meantime, progress on what may be called the electrical engineering front has been by no means negligible, and is likely within the near future to affect hospital practice, as well as nuclear research. The medical application arises from the fact that x-rays are produced whenever a beam of fast-moving electrons hits a solid target. This is the normal way in which x-rays are produced. What happens, in effect, is that the energy of movement which has been given to the electrons is released in the form of x-rays. It would be expected, therefore, that the higher the energy level to which the electrons are accelerated, the higher also will be the energy of the x-rays produced.

The first device for accelerating electrons to energies of ten million volts or above was the "betatron"—a magnetically operated "whirligig", due to Professor D. W. Kerst of the University of Illinois. Later, it was suggested both in Russia and the United States that, by a suitable combination of electrical and magnetic forces, electrons could be accelerated to still higher energies. To one such device the name of "synchrotron" was given, and in autumn 1946 the Ministry of Supply's Telecommunications Research Establishment at Malvern attained the distinction of being the first laboratory in the world to make a "synchrotron" work. The important point was the purely practical one that, with the same bulk of equipment, and the same magnet, they could produce electrons of twice as great energy as with the earlier "betatron" system of working.

So far, the Malvern team has got up to 12 million volts with "synchrotron" working, and has designed a 30 million volt equipment, which is already complete except for the magnet. It will probably be already in operation by the time that these notes appear in print—and, by the sudden stopping of the electrons, it will produce x-rays of the same high voltage.

The reason that doctors are interested is that x-rays produce secondary radiation within the body. The effect becomes greater, as might be expected, as x-rays of higher energy are used; and it means that an appreciably greater dosage can be produced inside the body than at the surface. This is, of course, precisely what is wanted in deep x-ray treatment, since effective dosage can then be increased, without any corresponding risk of surface burns. At 30 million volts, it is expected that the greatest dosage will be at a depth of about two inches, with a comparatively slow falling off thereafter, and that the maximum intensity of radiation will be about four times that at the surface. There are a good many points which will need to be checked up, and for this reason a preliminary programme of physical and biological investigation is being carried out. The principle, however, appears already to have been established, and within the next year it may be expected that the first test installations at hospitals will already have been made. After that, it will be a question of medical research to decide how far up in voltage it is worth going; and of engineering research to determine the most economical method of producing the necessary higher-energy electrons. Meantime, we know already that the "synchrotron" will do the job.

Cancer Yard-Stick

Cancer research has lately provided an interesting link between the methods of physics, chemistry and biology. This has taken the form of a new test by which it is suggested that the efficiency of any proposed cancer treatment can be investigated. The origin of the test lies, not in medicine itself, but in the science of genetics.

In brief, it has been known for some long period, that the chief vehicle for the conveyance of hereditary qualities from one generation to the next is provided by small bodies known as chromosomes, which can be made visible beneath the microscope within the nucleus of every living cell. These chromosomes are rod-shaped bodies, which are characteristic in size, number and shape for every form of life—and it is supposed that the "genes", the actual units of heredity, are located on them. The picture which has thus been obtained provides an explanation in general terms of the main facts of heredity. But it does not, in itself, account for the appearance of new "mutations"—of varieties, that is, which include qualities not directly derived from either parent. It was accordingly natural to look for possible external factors which might influence the normal course of heredity, by changing in some way either the chromosomes or the genes which they carry. One such agency was found in x-rays—although, under natural conditions, it may be cosmic radiation which does the job.

The effect of x-rays is, quite literally, to "knock the chromosomes about", and to do so with such violence, provided the correct dosage is used, as to interfere with the normal process of division by which the cells of the body reproduce themselves and are replenished. This, in turn, led to an explanation of the way in which x-rays, and for that matter radiation from radium, come to be effective in the treatment of cancer. The answer, surprisingly at first sight, is that there is no specific effect against cancer at all. The only reason that cancer cells suffer more, under x-ray bombardment, than do normal cells, is that they multiply at a higher rate—and it is during the division process that the chromosomes are most vulnerable. The probability that a cancer cell will be "caught" at this stage—or, more accurately, at one of the stages associated with division—is accordingly greater than for a normal cell.

This suggested, as a further sequel, that any other form of attack against cancer might operate in the same way. It was guessed therefore that, from the observed effect on the chromosomes, the probable efficiency of any suggested method could be quickly gauged. The first attempts to apply this technique have lately been made by Dr. C. D. Darlington of the John Innes Horticultural Research Institution, and Dr. P. C. Koller of the Cancer Hospital research unit, and are thought to be quite promising. It should perhaps be emphasised, however, that the promise is as a method of investigation rather than as a treatment, which it is not. A number of chemical substances which appear to have some effect on particular forms of cancer are, as it happens, under investigation at the present time. This is where the chemical link-up comes in. But it is probably more important for the future that a new yardstick has been found by which progress can be measured.

Structure of Wool

Another example in which progress in physical science has affected biology is provided by the structure of wool. The research weapon in this case has been the electron microscope, an article on which was included in *Science News I*. It is also quite a good illustration of the way in which additional evidence may lead to the scrapping of one scientific picture in favour of another.

The original picture was based partly on the use of x-rays to show repetitions of physical structure, and partly on the extent to which wool fibres expanded in water. It was due largely to Professor W. T. Astbury of Leeds, and so long as the available evidence was confined to these two lines of approach, it appeared both satisfying and satisfactory. In brief, it was thought that wool fibrils consisted of long chains composed of keratin molecules, and that the expansion of wool in water corresponded with the unfolding of these chains.

This was the simplest possible interpretation of the facts, as then known, and it was generally accepted as correct —until the electron microscope enabled wool fibrils to be directly photographed. Now that this has been done, workers under the Australian Council for Scientific and Industrial Research have been enabled to put forward a new picture which, although less simple and "pretty", is more likely to be correct.

They have found that wool fibres consist, not only of chain-like fibrils, but also of amorphous material which looks like so many loose beads thrown in a heap. In addition, the fibrils can be seen to be built up in sections, the size of which corresponds with that of the loose beads. The inference is that the basic unit is the bead, and that the fibrils consist of these beads, joined endwise together. It follows also that the physical theory of the stretching of wool, which had seemed so neat and cut-and-dried, will have to be reconsidered; and that the concertina metaphor, which has so often been used to describe it, will have to be abandoned. What does *not* follow is that there was anything the matter with Professor Astbury's earlier observation. Merely does it sometimes happen that a theory, which at the time appears the simplest, is proved later, and by further evidence, to be incorrect.

Microscope Progress

If the electron microscope is already proving its value, the optical microscope appears to be further from the end of its useful life than some in the United States have been ready to suggest. Two quite different developments have lately been attracting attention, either of which separately would offer quite considerable possibilities. The first, which came from Germany during the war, was the technique known as "phase contrast" microscopy. This, essentially, is a way of showing up the structure of a colourless material—for example, living tissue—without having to introduce artificial colour in the form of a stain. The objection to staining is the obvious one that, even if the stain does not kill the organism or cells which it is being used to show up, it is impossible to be sure that it does not affect them. And the advantage of the "phase contrast" method is that, apart from the illumination which is inevitable with any form of microscopy, one does not have to "do anything" to the organism in order to observe it. Incidentally, the microscope itself remains, in essentials, as before. The innovation is simply that a new optical trick has been added to its working.

The same cannot be said of the reflecting microscope, as developed by Dr. C. W. Burch of the University of Bristol. Here the change which has been introduced is of a much more radical kind. In place of lenses, he has used a system of mirrors to obtain his magnification. One of his main reasons for doing so is that, whereas the properties of a lens depend on the wavelength of light with which it is being used, those of a mirror do not. This means that it should be possible, in theory, to use such a microscope with radiation which extends well into the ultra-violet region—and which is of too short a wavelength for the human eye to be able to see. The point here is that the shorter the wavelength of the radiation used, the more detail should it be possible to observe.

The hope, accordingly, is that with the type of mirror system introduced by Dr. Burch, it may be possible for the optical microscope to approach more nearly the limits of resolution already achieved by the electron microscope.

Nor will this hope, if realised, be a mere duplication. Whether an electron beam is used, or extreme ultra-violet radiation, some effect is likely to be produced on the object under examination. For this reason, it would be reassuring, at least, to have two independent methods available.

The main difficulties are practical. In order to produce a high-power reflecting microscope, it is necessary to work at least one, and preferably two, mirrors to special non-spherical shapes. Also, as with other optical equipment, this must be done to the highest possible accuracy. In describing lately the first such microscope which he has made, Dr. Burch stated that it was necessary to "have a great deal of patience, and preferably a little insomnia". In his second, which he expects to occupy him for two years, he proposes to "go to the limit". He will build it in collaboration with Mr. W. J. Bates, also of Bristol University.

"*Memory*" *in a Mercury Tube*

Although much has been published about the wonders of valve-operated calculating machines, it is only lately that the most interesting fact has been made known about the Automatic Computing Engine (A.C.E. for short) now under construction at the National Physical Laboratory, Teddington. This is the nature of the "memory" with which it is to be provided.

The question which comes first, however, is—why a memory at all? The simplest answer is that even a valve-operated machine does its calculations by stages, like any other performer in arithmetic; and, unless at every point it "knows" what to do next, much of the value of its speed of working is lost. It is much better that it should be "told" in advance what to do, and then left to get on with the job. And that implies that it must be able to store up, or "remember", the instructions given it. In addition, it is of obvious advantage that it should be able, without stopping in its work, to keep some record within itself of intermediate answers, so that these as well as the final answer can be produced if required. Finally, if it is to "save itself trouble" by making use of any of the standard forms of mathematical table, it must be able, again, to store up and reproduce any information of this kind which is given to it.

The form of A.C.E.'s "memory" is dictated by its working treatment of numbers. These are represented, in a simple code system, by the presence or absence of electrical pulses at prescribed intervals of time, roughly every millionth of a second. Anything which the machine has to "remember" will take the same form—a series of pulses, punctuated by "not-pulses", at regular intervals. Since electrical changes travel, in any normal circuit, at speeds of the same order as that of light, the first requirement is clearly to find some way of slowing up their progress, and at the same time perpetuating the particular pattern of pulses which is to be preserved. This is done by providing a sort of endless chain circuit in one leg of which a delay in transmission is deliberately introduced. The delay-leg consists of a tube, about five feet long, which is filled with mercury, and down which the sequence of pulses is sent in the form of mechanical vibrations. Translation into this new form is achieved by a piezo-electric crystal, such as is used to provide the pick-up unit of a radiogram.

This, however, is only one leg of the memory circuit. At the far end of the mercury tube, a second crystal translates the pulses back again into electrical form. By this time, they are getting slightly distorted, although still identifiable as pulses or not-pulses, which is all that is required. They next pass to a "wash-and-brush-up" unit. Here they are inspected and identified, and passed out again in standard and correct shape to re-enter the mercury tube at the original end. In this way the pulse pattern can be kept circulating for as long as may be necessary, without any cumulative change either in strength or shape. The electrical part of the roundabout is covered practically instantaneously. The stage of physical vibration in the mercury tube occupies roughly one thousandth of a second; so that, in every second, the pulses which are being "remembered" will make a thousand circuits of the system. Also, since the pulses are a millionth of a second apart, the number of pulses which can be stored up in any one such tube is also about a thousand. In all, it is proposed to provide A.C.E. with 200 of these memory tubes, so that the complete equipment will be able to "carry in its head" some 200,000 pulses. And, of these, some will represent instructions, others intermediate answers for later use or reproduction, and others again trouble-saving numerical tables.

Upper Winds

Meteorology is one of those branches of science which has long received more abuse than bouquets. One reason is that, with weather forecasting an official service, it is only human nature that we should remember its failures with more readiness than we do its successes. Another, more fundamental, is that the ocean of the air is of enormous extent and that, except at ground level, comparatively little has been known hitherto about its behaviour.

In two different directions radar is now coming to the aid of the meteorologist. The first of these was a wartime development and, in its way, quite an obvious extension of radar's normal use. This was the employment of radar sets to follow to greater distances the small balloons which are regularly released at selected weather stations, to give an indication of upper air movements. Apart from the greater ranges which are obtainable with radar methods, there is the further advantage that these test balloons can now be followed under conditions when visual observation would be impossible. In this way, knowledge of wind movements up to a height of five miles or so has been greatly increased.

The second development is more recent. It is an extension of the use of radar to record the arrival of meteors in the earth's atmosphere, at heights of 52 to 60 miles above the earth. The connection with meteorology is that it is not the meteor itself which is observed, but the electrically charged trail which it leaves in the air behind it. Usually, this is of only short duration. Within a fraction of a second, it melts away and can no longer be detected. But in a few cases, such trails have persisted for long enough for their rate of drift—representing the movement of the air at the height in question—to be measured. The greatest speed so far reported was estimated at between 350 and 400 m.p.h. This, incidentally, is the highest wind speed yet known. But more important than the setting up of records is the upwards extension in knowledge of the atmosphere which this new method of observation will make possible.

Prospecting—New Style

Prospecting for oil is beginning to acquire quite a Jules Verne flavour—largely owing to the extent to which under-sea fields are now being investigated. The first step towards flamboyance was taken in Russia in 1936, when a magnetic survey was carried out from the air over a land area. This has the great advantage that variations in the earth's magnetic field can be quickly mapped over a large region, and that irregularities due to small surface features are conveniently smoothed out. The method was further developed during the war for submarine detection, and now appears to be fully satisfactory—apart from the one serious qualification that it is one thing to be confronted with a map showing magnetic variations, and quite another to deduce from it the presence of oil.

At the opposite extreme comes the use of "bathyspheres" —closed diving chambers maintained at normal atmospheric pressure—which was commended by A. Van Weelden at a recent meeting of the Institute of Petroleum. The bathyspheres are provided with a tripod-type base to give stability, and the job of the occupant is to chart the variation in the strength of gravity, when he is moved from one position to another over the sea bed. Ordinary diving bells have also been used for the same type of measurement, although these are naturally much more limited as to depth of operation.

The remaining method, like the gravity survey, is already well tried in normal land prospecting. This is the seismic survey, in which an explosion is used to initiate miniature earthquake waves. Seismographs, similar to those used in earthquake recording, are then employed to record the travel of the waves produced, which vary according to the local geology. In comparatively shallow water, the seismographs are lowered in water-proof casings to the seabed, and the "shot-hole" is cased from above the level of high tide to a sufficient depth to prevent leakage of sea water. Difficulties obviously increase with the depth. It is considered, however, that useful information can be obtained out to the hundred fathoms line, which is generally taken as marking the edge of the continental shelf.

Apart from submarine prospecting, it can be taken for granted that the magnetic method of air survey will be widely used in future, both over Antarctica and other regions which have so far been inadequately surveyed for minerals. It should perhaps be pointed out, however, that whatever method of survey is used, interpretation will always remain difficult, in the absence of fairly complete geological information—and that can only mean test drilling.

Another substantial improvement in geophysical prospecting has been in the ease and speed with which gravity readings of the highest accuracy can now be taken. The time needed for a single observation has been reduced from five hours to, literally, a minute, and the weight of the equipment necessary from more than two hundred pounds to less than fifty. Recent oil prospecting in Great Britain has been greatly speeded up as a result, and these advantages would clearly be of even greater value in difficult country.

Radio Lens Problem

An unusual problem has been presented to physicists by a form of radio transmitting aerial which was developed by the Admiralty Experimental Establishments during the war, but only lately shown in public. This particular set was designed for operation on 3.2 centimetres, and one of its objects was to look as little like a radio transmitter as possible. Removed from its box, the complete aerial assembly has the appearance of the side lamp of a car. And, in fact, the funnel part of the "lamp" turned out to be the mouthpiece out of which the waves were literally being poured. What was unusual, for a radio aerial, was that the "lamp" was fitted with a lens, made of polystyrene, a plastic material which has been widely used as an insulator. Even this would not perhaps have attracted much comment in these days, but for the fact that the diameter of this lens was no more than about 6 centimetres—the equivalent of about two wavelengths, on the frequency at which the transmitter had been operated. The oddity will be obvious to any physicist. According to all the rules, a lens should not act as such, unless its dimensions are large compared with the wavelength it is to refract.

None the less, say the Admiralty scientists, this particular lens really does behave as a lens should if of larger size; and the radio waves from the lamp really are beamed, as light waves would be, if they had been similarly focussed. The point is not, admittedly, of any major importance. It is none the less illuminating, in this age of the higher physics, that competent research men should find difficulty in explaining the working of so comparatively simple a piece of equipment.

Having said so much, it should perhaps be added that various other types of unorthodox aerial have been successfully explained. The one which was most used in practice was a tapered polystyrene rod about ten inches long (eight wavelengths). This produces as directional a beam as would quite an elaborate array of normal types—and the radiation proceeds in the direction that the rod is pointing, and not, as with a conducting aerial, at right angles to it. Yet another unusual aerial, the theory of which has been fully worked out, consists of nothing more than a roll of cardboard, with the end left open in the direction of radiation. This also has a strongly beaming effect, at the frequencies for which it is intended, although for obvious reasons its use under outdoor conditions is not recommended.

Biochemical Aspects of the Soil*

PROF. J. H. QUASTEL, F.R.S.

Introduction

LAND surfaces almost everywhere are covered with a layer of unconsolidated debris which, above the bedrock, may be very shallow or hundreds of feet in thickness. The debris has been formed through transportation, or deposition, by water or ice or by the wind, or by weathering. Physical and chemical changes continually take place in this variable stratum of debris, which becomes a soil only as soon as micro-organisms and plants become incorporated in it and begin to bring about their biochemical changes. The stratum of soil gradually develops a fairly well defined system of layers, termed in soil nomenclature "horizons", and the system of horizons which makes up the stratum is called a soil "profile". The characteristics of profiles are of great importance in soil surveys and soil classification. Usually the uppermost horizon of a soil profile contains much organic matter arising from the deposition of leaves and general decomposition of plant material; it has a dark colour in consequence. Under the horizon containing variable quantities of organic matter, comes the subsoil which, whilst weathered, contain very little organic matter. The subsoil has a depth of 3 or 4 feet, in temperate regions, and merges into another horizon consisting of the original soil material. The soil is thus a natural body developed by weathering and its characteristics at any part of the land surface are determined by local physical, chemical and biological changes. These characteristics largely influence the fertility of a soil.

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* This article is based upon, and contains the substance of, a lecture delivered by the writer before the Royal Institute of Chemistry on April 27, 1945.

The soil is largely composed of mineral materials, organic matter, air and water. The particles of mineral matter differ greatly in size, from those that are coarse, such as gravel and sand, to those that are in a fine state of division such as silt and clay. The organic matter is variable in constitution, as it represents all stages of biological breakdown of plant material and all the products of metabolism and autolysis, due to soil organisms. This organic matter plays a fundamental part in developing the crumb structure of soil so important to soil fertility. The crumbs of soil exhibit pore spaces varying greatly in dimensions and occupied largely by water and air. Water is held in these pore spaces, and in the films of water at the soil-crumb surfaces biochemical changes of great importance to plant growth are continually taking place. These changes are influenced by the access of oxygen to the water films; if the access of oxygen is poor, as for example in waterlogged conditions, anaerobic changes occur whose biochemical characters are very different from those obtaining where oxygen access is unimpeded. The farmer refers to soils as varying in "tilth", a good "tilth" being defined as the optimum physical state for crop production. An example of a soil in good tilth is the black prairie soil of which the larger proportion is made up of granules from one to three millimetres in diameter. Such granules are stabilised by a coating of waxy organic matter. The soil has a high proportion of large pores and is readily permeable to air and water. Soil fertility is very much dependent on soil structure, for clearly plant roots, in order to develop most favourably, must have ready access to oxygen, water and other nutrients. The chemist has been greatly concerned with determining the availability in soils of essential plant nutrients such as compounds of nitrogen and phosphorus or of potassium ions and ions of many metals, which are partly held in combination by the mineral matter (especially the clay) of soil and partly by organic matter, which however is continually altering its character by decomposition. If the soil is deficient in these nutrients, they must be supplied to ensure good crop production; or if through some character of the soil, nutrients are present but are not available to the plant, means must be found to make them available.

The microbiologist has been largely concerned with discovering the various types of organisms which exist in soil and the types of chemical changes which they bring about. These changes vary very greatly, for they involve the very important processes of transformation of the free nitrogen of the air into substances which nourish both microbe and plant and ultimately therefore all animal life; they involve processes affecting the states of combination of phosphorus and sulphur in soil and the manner in which iron or manganese or oxygen or carbon dioxide may take part in chemical reactions which influence the developments of micro-organisms and plants.

The study of the chemistry of all such changes accomplished by biological means under the conditions prevailing in soil forms the subject of soil biochemistry. The writer proposes in the ensuing brief article to examine a few aspects of, and some recent results obtained by investigations in, soil biochemistry.

General considerations

Soil may be considered from at least the two following points of view:

(1) It may be thought of pre-eminently as a medium for the growth of crops, all processes taking place within it being judged primarily from their importance in influencing crop production.

(2) It may be thought of as a complex biological system in which hosts of organisms are competing with each other, often for a limited supply of food. They exercise profound effects on each other's development and chemical activities, and establish between themselves a balance which is forever changing with every change in the physical and chemical environment of the soil. In such an equilibrium, the plant

plays an important part. The root cells form part of the complex cell system of the soil and the development of the plant becomes a function of the equilibrium condition set up in the soil.

This second point of view, in fact, embraces the first, but allows for a wider and more fundamental scope of investigation. The soil is studied, for its own sake, as a biological whole. Its metabolic events, under defined experimental conditions, may be investigated in a manner similar to those of any other complex system of cells, such as are presented by isolated animal and plant tissues. Progress in agricultural chemistry within the last hundred years has been due in the first place to the development of methods for determining the composition of plants and of soils, and in the second place to the recognition that soil micro-organisms are responsible for a great variety of highly important chemical processes taking place in the soil.

Liebig's views, faulty as some of them were, gave a great stimulus to soil investigation. They were based upon analytical studies and directly led to the work of Lawes and Gilbert at Rothamsted, which formed the foundation of the great fertiliser industries of to-day. Liebig's greatest handicap, however, was the fact that soil microbiology had not yet made its contribution to agricultural chemistry. The demonstration by Hellriegel and Wilfarth in 1886 that bacteria in soil infect legumes (plants of the bean, pea, clover family) forming nodules which, on the roots of the plant, are capable of fixing nitrogen,* followed seven years later by Winogradsky's discovery of a soil organism which can fix nitrogen independently of the plant, served to focus attention on soil micro-organisms as essential factors in soil chemistry.

The chemical aspects of soil microbiology have assumed increasing importance as the factors contributing to crop production have been unravelled. It is no exaggeration to state that there is now no aspect of soil microbiology without its bearing on the chemistry of the soil. This may be seen not only in the transformations that nitrogen undergoes in soil, but also in the changes that affect other elements essential to plant life: sulphur, phosphorus, iron or manganese. The breakdown of organic matter so essential for the development of the tilth or structure of a soil, the varied organic transformations that convert a chaos of complex materials in the soil into something rather less complicated, the production of carbon dioxide—which plays its vital part not only in the chemistry and physics of soil but in restoring to the atmosphere the carbon essential for plant life—all these are the direct results of biological processes in the soil. The bacteria, in view of their great preponderance in numbers and of their known great chemical activities, are held responsible for many of the biochemical changes taking place in the soil. In the transformation of organic matter, fungi also have activities which may, under certain conditions, exceed those of the bacteria.

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* That is, of converting the inert nitrogen gas of the atmosphere into ammonia and nitrates, valuable fertiliser salts for the soil, and foodstuffs for the plant.

The last twenty years have seen a great development in our knowledge of the biochemistry of bacteria and fungi. The isolation and investigation of these organisms in pure culture have not only resulted in increased knowledge of their specific chemical activities, but have also led to discoveries that have rapidly advanced fundamental biochemical knowledge. The studies of the processes of fermentation and of oxidative changes in yeasts and in bacteria have given a new insight into the mechanisms of breakdown of organic substances in the living cell, have thrown light on the mode of enzyme action and have led to the discovery of the parts played by a variety of vitamins in metabolic processes. Studies of soil bacteria and fungi have resulted in the preparation from them of substances whose antibiotic effects are of immense importance in medical therapy.

How do these results, obtained in pure culture and under defined experimental conditions, important as they are in their fundamental character, help in the elucidation of processes taking place in soil ?

The soil has an extensive microbiological population, made up of great numbers of species of bacteria and of genera of fungi, actinomycetes and algae as well as of numerous families of protozoa, nematodes and other invertebrates. Some of the soil organisms have relatively specific effects as in the fixation of nitrogen and the conversion of ammonia into nitrite, or of nitrite into nitrate, but frequently a large variety of organisms can attack a single substance. Thus the decomposition of cellulose can be brought about by many kinds of bacteria, having many different morphological and physiological characteristics, by fungi belonging to widely different genera and by many actinomycetes and other organisms. Proteins and fats may be attacked by complex soil populations. The manner of breakdown by isolated organisms in pure or even in mixed cultures of proteins, carbohydrates or fats may be followed in detail, but there can be no assurance that the same mode of breakdown occurs under soil conditions until experiments with soil have actually shown this to be so. The environmental conditions in soil are altogether different from those in the media in which metabolic studies of micro-organisms are usually studied.

Some conception of the enormous population of micro-organisms in soil is provided by the fact that there may be as many as 5,000,000,000 bacteria per gram of soil. This corresponds to a weight of over four tons of bacterial substances per acre of soil. The numbers of bacteria fluctuate very greatly, depending on availability of food supply, moisture, aeration conditions, temperature, hydrogen ion concentration of the soil and other factors. Direct counts under the microscope made by Conn in 1918 gave numbers of bacteria of the order of 250×10^6. Another method gave counts ranging from $1{,}280 \times 10^6$ to $2{,}160 \times 10^6$. Gray and Thornton improved the technique of bacterial counts and obtained direct counts of the order of $4{,}000 \times 10^6$ bacteria in a gram of manured arable soil. Such figures were over a hundred times those obtained by the plating technique. Protozoa may reach figures of the order of 1,000,000 per gram of soil (amoebae 280,000, flagellates 770,000, ciliates 1,000, estimated on a neutral manured arable soil at Rothamsted). Algae may exceed 100,000 per gram of soil. Actinomycetes and fungi, both of which are difficult to estimate, may have a combined weight in the soil equal to that of the bacteria. According to Waksman and Starkey the numbers of actinomycetes range from a few thousands to many millions per gram of soil, whilst fungi may reach over 100,000 per gram.

In such a complex microbiological population there must exist numerous as yet unknown chemical interrelationships affecting metabolic behaviour and cell proliferation. Symbiotic associations take place and antibiotic developments occur. Growth factors and cell poisons are elaborated There is a constant disintegration of cells and a constant growth of new cells greatly influenced by, and possibly dependent upon, the breakdown products of the old. Cell adaptation occurs and the enzymic equipment of cells undergoes change in response to changes in their environment. The study of an individual species of organism remote from its normal environment in the soil can do no more than indicate its possible metabolic behaviour in the complicated biological system presented by soil. To the study of the biochemistry of soil *as a whole* we must ultimately turn for our data on its metabolic events.

NITROGEN METABOLISM IN SOIL

Nitrogen Fixation

Let us now consider some aspects of nitrogen metabolism in soil. Boussingault's early experiments in 1837 made it clear that fixation of atmospheric nitrogen takes place during the development of legumes such as clover, peas, and lucerne, whereas these fixations do not occur during growth of other crops, such as wheat. Liebig (1843, 1852), opposed to the view that free nitrogen of the air is assimilated by the plant, considered that atmospheric ammonia is primarily involved. Ville (1885) showed that this cannot be so. The classical work of Hellriegel and Wilfarth in 1886 cleared up a complicated situation. They showed that soil bacteria infect legumes, forming nodules which enable the plant to use atmospheric nitrogen. These bacteria, known as *Rhizobia*, were isolated in pure culture by Beijerinck. They were thought at first to be capable of fixing free nitrogen in the absence of the plant, but later work disproved this. Since there is no evidence that the host plant, in the absence of the rhizobia, can fix atmospheric nitrogen, it follows that some chemical interchange between the plant and the bacteria must take place *in vivo* and be largely responsible for nitrogen fixation. The excised nodules do not themselves take up nitrogen and the chemical association between nodule bacteria and plant, which results in nitrogen fixation, is unknown.

Much, however, is known of the biological aspects of this symbiosis or association between rhizobia and host plant. Details of these aspects are outside the scope of this article, but one important fact proper to the study of soil metabolism should be mentioned. When the seed of a legume germinates in a soil containing rhizobia, the latter are attracted to the region of the developing root hairs. There, a product of the metabolism of the rhizobia produces a deformation or "curling" of the root hairs. Such curling is induced by a specific chemical substance, for extracts of the bacteria are as effective as the living cells themselves. At the site of the deformation of the root hair the rhizobia invade the root tissue and proliferate, stimulating cell division in the neighbouring plant cells, and a nodule is formed.

There is evidence that the deformation of the root hair, essential as a preliminary to the invasion of the rhizobia, is accomplished by indole-acetic acid, a common metabolic product of bacteria. It is known that indole-acetic acid and related plant "hormones" have but a transitory existence in soil, owing presumably to speedy decomposition by other bacteria. It follows therefore that metabolic conditions in the soil in the near neighbourhood of the germinating legume must be such as to enable a sufficiently high concentration of indole-acetic acid to accumulate to bring about the curling response in the root hairs. Though such a concentration may be small—of the order of one part in 100,000,000—a relatively high rate of production may be necessary to counteract the local destructive forces at work. It is known too that indole-acetic acid at low concentrations may be toxic to seed germination and that trypthopane in presence of soil bacteria will induce such toxicity. Thus metabolic conditions in soil will greatly influence seed germination.

Let us turn now to non-symbiotic nitrogen fixation. Winogradsky in 1893 found that an anaerobic soil organism, *Clostridium pastorianum*, will fix free nitrogen when supplied with the sugar glucose, the amount of nitrogen fixed being proportional to the amount of glucose broken down. The fixation of nitrogen is inhibited by the presence of ammonium salts and this inhibition may be counteracted by an increase in the glucose concentration. Thus the ratio of carbohydrate to combined nitrogen determines the rate of fixation of nitrogen. An interesting feature of this organism is that it loses its power of nitrogen fixation during prolonged cultivation on artificial media, but the power is restored by culture of the organism once again in soil. The soil factor responsible for the renewed ability of *Clostridium* to fix nitrogen is unknown.

Beijerinck in 1901 isolated from soil and mud two aerobic organisms capable of fixing atmospheric nitrogen. They are *Azotobacter chroococcum* (the more common form) and *Azotobacter agilis* (the motile variety). Unlike *Clostridium*, *Azotobacter* does not lose its power of fixing nitrogen on prolonged culture on synthetic laboratory media. A striking fact concerning *Azotobacter* is that it requires for its metabolism the presence of traces of molybdenum or vanadium. A positive effect of Mo on the growth of the organism can be observed at a concentration of 1–3 parts in 10^6. Burk and Horner have found that molybdenum is not only required for the assimilation of free nitrogen, but is also necessary for the utilisation of combined nitrogen (in the form of asparagine or nitrate) by this organism. Tungsten will to some extent replace molybdenum. *Azotobacter* and *Clostridium* are apparently the most widely distributed non-symbiotic nitrogen-fixers in soil, and they are found also in salt and fresh water, often in association with algae.

In arid soils relatively poor in organic matter, micro-organisms form more than their usual proportion (about 5 per cent) of the organic matter, and this is chiefly due to the marked development of *Azotobacter* under the alkaline or saline conditions of such soils. It is stated that in the chestnut soils of south-east Russia, where almost the whole of the organic matter is in the form of micro-organisms, there are up to 900,000,000 *Azotobacter* cells per gram of soil.

The most important single factor influencing nitrogen fixation in soils is the presence of nitrate. Both with *Clostridium* and *Azotobacter* the presence of utilisable combined nitrogen diminishes the rate of nitrogen fixation, ammonium or nitrate being effective in this way. Inhibition of fixation by *Azotobacter* is complete in the presence of ammonium nitrogen at a concentration of 0.5 mg. N per 100 ml. The presence of nitrate or of ammonium salts in the soil also makes legumes resistant to attack by *Rhizobia*, fewer root hairs and nodules being formed. The net result is that, when excess combined nitrogen is available in the soil, little or no fixation of atmospheric nitrogen takes place. The presence of carbohydrates diminishes the effect due to the combined nitrogen.

Various factors in soil influence nitrogen fixation, amongst which may be mentioned moisture, hydrogen ion concentration, aeration, soil structure, temperature, and the addition of fertiliser salts (*e.g.* phosphates and calcium). Humus has a beneficial effect on *Azotobacter* growth, possibly owing to the iron contained in it, though traces of molybdenum present may be a responsible factor.

It has to be remembered that in soil there is an abundant flora of bacteria and fungi, other than the nitrogen-fixers; they will compete for the carbohydrates, which are the main sources of energy for *Azotobacter* and *Clostridium*. It has been estimated that, associated with the decomposition of 100 parts of available organic matter free from nitrogen, there may be fixed by the non-symbiotic bacteria about one part of nitrogen. This works out at only about eight pounds of nitrogen fixed per acre of soil receiving a liberal application of plant residues per year, though it has been stated that as much as 40 lb. of nitrogen per acre may become added to some soils annually as a result of the activities of the non-symbiotic nitrogen-fixers.

Ammonia Formation

It is known that the nitrogen compounds in plant residues are broken down in soil to form ammonia so long as the ratio of carbon to nitrogen in the organic matter does not greatly exceed 10. Proteins and other nitrogenous compounds are broken down in soil by a variety of organisms, the ultimate nitrogenous end-product being ammonia. Whether the ammonia appears or not depends on the rate of proliferation of other organisms in the soil requiring the ammonia nitrogen for their own synthetic operations. If there is ample utilisable non-nitrogenous material, such as carbohydrates, present, the ammonia nitrogen will not appear, as it is entirely used for building up fresh bacterial or fungal matter. Proteins being rich in nitrogen yield ammonia in relatively large amounts. The production of ammonia in soil was long attributed to the large sporing groups *B. mycoides* and *B. subtilis*. It is now known that non-sporing organisms of the *Ps. fluorescens* group are active ammonia formers.

It is evident that many organisms may be involved in ammonia formation, the mechanism of which in most instances is unknown. If the proteins are broken down to amino-acids, these may yield ammonia by the action of oxidase enzymes in the organisms, increasing knowledge of which is now being derived from the study of animal tissues. Little is known, however, of the modes of breakdown of nitrogenous organic matter in soil and there is here an interesting and fruitful line of investigation.

Nitrification

This important metabolic process of soil whereby ammonia and organic nitrogenous material are converted finally to nitrate was shown by Schloessing and Muntz, from a study of the purification of sewage water by land filters, to be a biological process. Warington showed that soil nitrification is inhibited by application of chloroform and carbon disulphide and described two sets of organisms apparently involved in the process, one which converted ammonia to nitrite and the other nitrite to nitrate. In 1890 Winogradsky isolated the responsible organisms. Warington made it clear that the final fate of nitrogen in the soil is the production of nitrate, which thereby becomes the main source of nitrogen for the plant. Progress since the end of last century has been extraordinarily slow. Stevens and Withers in 1910 showed that nitrification in the soil differs in at least one important aspect from that in the artificial media first elaborated by Winogradsky. They demonstrated that nitrification in soil is inhibited far less by the presence of added organic matter than in laboratory media. They had already shown that nitrification of cotton-seed meal and of ammonium sulphate is more rapid under soil conditions than in culture media. In 1915 Allen and Bonazzi showed that soil, even ignited soil, is superior to sand in supporting nitrification, and a number of workers (Albrecht and McCalla, Conn, and Conn and ZoBell) claim that the presence of colloids in culture media influences bacterial behaviour.

Meyerhof's extensive studies on the metabolism of *Nitrosomonas* and *Nitrobacter*, the organisms respectively responsible for the conversion of ammonia to nitrite and of nitrite to nitrate, have thrown much light on their behaviour in artificial media. Ignorance, however, of the details of nitrification processes in soil is largely due to the dearth of suitable experimental work on the soil itself. There is an immense literature on field and pot experiments showing the nature of the end products after application of organic nitrogenous matter. This work is of high practical importance, but it helps little towards elucidating the mechanism of nitrification in soil. Attempts have been made to correlate soil nitrification with soil fertility, but the general relations between the results obtained with culture media and those obtained with soil are obscure. Albrecht and McCalla state that "the complexity of sand, silt and clay mixture as soil prohibits an accuracy great enough to encompass all the various chemical aspects of so delicate a process as nitrification."

It has long been apparent that there is need for a quantitative study of nitrification processes in soil, and indeed there is need for a detailed study of all metabolic processes known to proceed in soil, under the conditions actually obtaining there.

For an accurate study of such metabolic events it is essential to have an apparatus which will ensure standardisation of soil conditions and therefore reproducibility of results. Many observations have shown how difficult it is to secure reproducibility of results without the most careful control of conditions. There are difficulties due to the heterogeneity of the soil, to variations in the water content, to variations in oxygen penetration in various parts of the soil, to alterations due to its handling for analytical purposes.

A fresh method of approach has been made by Lees and the writer by devising an apparatus whereby a column of soil (in the form of sieved air-dried crumbs) is perfused with oxygenated, or aerated, fluid by a circulatory technique. This enables the same soil solution to percolate through the soil for an indefinite period. The underlying idea is to treat the soil as though it were an intact organ and to perfuse fluid through it as though it were an isolated living heart or kidney in the preparations familiar to the physiologist. The soil perfusate is adequately mixed and aerated and the perfusion is intermittent, so that waterlogging of the soil does not take place. The process is continuous and may be maintained for an indefinite period. The substance whose metabolism in the soil is being investigated is dissolved in the perfusion fluid, or mixed with the column of soil.

This technique for investigating soil metabolism has many advantages including the following:—

(1) The water content of the soil is kept constant and the water is homogeneously distributed in the soil throughout the entire experiment.

(2) Maximal aeration of the soil is effected.

(3) The soil itself is not handled in any way during the experiment, analysis being confined to the constituents of the perfusate. The soil may be examined after any arbitrary time for analysis of ions adsorbed onto the soil.

(4) Substances such as biological poisons or inhibitors can be added to the soil solution during the course of an experiment and at any period corresponding to a known metabolic activity of the soil.

(5) Gases entering the apparatus can be controlled; metabolic events in atmospheres of oxygen, or nitrogen, or carbon dioxide or mixtures of these gases may be studied.

(6) The soil solution can be replaced at any given time by the solution of any metabolite of which the transformations are the subject of study.

The velocities of metabolic events in the soil may be accurately studied by this technique. The soil is, in fact, treated as a biological whole, every effort being made to ensure constancy of the environment in which the soil is exercising its metabolic functions.

Using this apparatus it was easy for us to show that the transformation of ammonia into nitrate is biological. This was indicated from the speed of the transformation, which followed the logarithmic "auto-catalytic" curve typical of bacterial growth, and from the effects of biological poisons.

Further experiments gave rise to the conclusion that the rate of nitrification of a given quantity of ammonium sulphate is a function of the degree to which the ammonium ions are adsorbed onto or combined in the soil, on its base-exchange complexes. The greater the amount of adsorption, the faster was the nitrification. This was shown by comparing the rates of nitrification of soils having different amounts of ammonia adsorbed upon them. The only tenable explanation of the results was that the adsorbed ammonium ions are those which are preferentially nitrified by the soil organisms. This led to the prediction that the addition of sterile soils to a nitrifying soil would increase its rate of nitrification in proportion to the base-exchange capacities of the added soils; this prediction was verified.

The interpretation of these results is that the nitrifying bacteria grow on the surface of the soil crumbs at the sites where ammonia is held in base-exchange combinations, and proliferate at the expense of such adsorbed ammonium cations. The rate of proliferation is proportional, therefore, to the area of soil surface on which ammonium ions are adsorbed or combined and is thus a function of the base-exchange capacity of the soil.

The fact that proliferation of the nitrifying organism takes place only at those specific sites of the soil surface where ammonium ions are adsorbed leads to the conclusion that when all these sites of the surface have been occupied, further growth of the organisms will not occur except to replace cells which have died and disintegrated. Remarkably few living nitrifying cells enter into the soil solution. This leads to the conception of a bacteria-saturated soil; that is to say a soil where the area of growth is limited and cannot be extended owing to full occupancy of available sites for proliferation. Such a soil should break down substrates, used only by the organisms which enrich the soil, at constant rates, and should not show the familiar logarithmic course of metabolism which obtains during proliferation. A bacteria-saturated soil has many of the properties of a biological catalyst. It decomposes a substrate at a constant rate which shows no initial lag period, until the amount of substrate falls below a certain concentration, after which further decomposition seems to follow the unimolecular law.

A very important use may be made of bacteria-saturated soils. They may be made to yield information as to whether any given substance is broken down by the cells which saturate the soil. For example it may be asked whether methylamine which is quickly nitrified by soil organisms is converted into nitrate by nitrifying organisms alone or whether additional organisms are required for a preliminary attack on the methylamine. To answer this question a soil is prepared which is saturated with the bacteria which convert ammonium ions into nitrate. With such a soil nitrate formation is perfectly regular and steady in time. This bacteria-enriched soil is now washed with water to free it from nitrates and it is perfused with methylamine. If the nitrifying bacteria themselves convert methylamine into nitrate the rate of conversion will be constant with no initial delay period. If they cannot bring about this conversion and if another set of organisms must develop prior to nitrification, there will take place an initial lag period followed by the familiar logarithmic increasingly speedy course of nitrification. The experiment proves conclusively that, in the soil, nitrifying organisms cannot themselves convert methylamine into nitrate. This technique is now being used for exploring the abilities of nitrifying organisms to break down a variety of nitrogenous substances.

Attention may now be given to the remarkable bacteriostatic* effects of potassium chlorate on the organisms that convert nitrites into nitrates. Quite small concentration of potassium or sodium chlorate (*e.g.*, $M/10^6$, or about 1 in ten thousand), have the power of preventing the development of *Nitrobacter*, whilst that of *Nitrosomonas* proceeds undiminished. The result is that when nitrogenous substances are nitrified in soil in the presence of small quantities of chlorates, nitrites but not nitrates accumulate.

Potassium chlorate acts as a typical bacteriostatic substance. This may be shown by adding it to a soil already enriched with nitrite-oxidising organisms. The presence of chlorate does not poison, or interfere with, the oxidation of nitrite to nitrate. With a *bacteria-enriched soil* the conversion of nitrite into nitrate proceeds at a constant rate uninfluenced by concentrations of chlorate which inhibit proliferation of the organisms involved. Further investigation of the phenomenon of chlorate bacteriostasis indicates that chlorate has the effect of greatly increasing the initial delay period shown by *Nitrobacter* in the course of its proliferation. Ultimately even in the presence of chlorates, so long as these are not in too high a concentration, nitrite is attacked and oxidised. Further work has revealed the fact that chlorate bacteriostasis may be neutralised by the actual presence of nitrates, which appear to act in a specific manner. Explanations for these phenomena are still lacking.

Manganese Metabolism

Let us now consider an entirely different aspect of soil metabolism. It is known that in addition to nitrogen, phosphorus, sulphur, calcium, magnesium, potassium and iron, which the plant must obtain from the soil, the elements manganese, copper, boron, and zinc are also necessary for healthy plant growth and even such elements as cobalt, molybdenum, tungsten, vanadium and selenium are reputed to have beneficial effects on certain species of plants. The amounts of some of these elements required for the healthy nutrition of the plant may be exceedingly small. One part of boron in twelve millions in a nutrient solution in which beans are grown will suffice to maintain them in good health. A concentration of one part of molybdenum in a hundred millions in a nutrient solution will ensure vigorous growth to the tomato plant. Deficiencies of these substances, as well as of major elements such as nitrogen, phosphorus or potash, lead to a great variety of plant diseases.

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* *i.e.*, it prevents the organisms from multiplying, but does not kill them.

Now it does not follow that if an essential element is present in the soil it is necessarily *available* to the plant.

Manganese is essential for healthy plant life. Its deficiency in soil (and soils rich in organic matter and lime are prone to this deficiency), leads to plant diseases such as grey speck of oats or marsh spot of peas. Its deficiency may cause a substantial reduction in the yield of a potato crop or complete failure of an oat crop. But many of these deficient soils—as diagnosed by inspection and analysis of the crop—often contain relatively large quantities of manganese. Thus it is apparent that manganese exists in the soil in at least two forms, of which only one is available for the plant. So far as is known it is only the base exchangeable manganese—manganese cations,[*] most probably wholly in the bivalent form—which is available for the plant. Manganese dioxide clearly is not available for a plant, for this substance is known often to be present in "manganese deficient" soils.

The question now arises as to why certain soils containing ample quantities of manganese are "manganese deficient" and why other soils containing much less manganese are "manganese available". This question is intimately connected with the metabolic transformations which manganese undergoes in soil.

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[*] Manganese atoms exist in solution as electrically charged particles, each carrying two units of positive charge (bivalent), Mn^{++}, or three Mn^{+++}, or even four Mn^{++++}. Increase of the positive charge is termed an oxidation.

It has been shown by Mann and the writer that when manganous (Mn^{++}) sulphate is perfused through soil, oxidation of the manganese takes place. This oxidation in neutral or slightly alkaline soils (pH 6.0 – 7.9) is almost entirely accomplished by the micro-organisms present. This is shown by the following facts:—

(a) The rate of oxidation of manganese in soil at 70°F. follows the logarithmic or autocatalytic course expected if proliferating organisms are responsible for the oxidation.

(b) The rate of oxidation in soil is greatest at a certain concentration of the manganese, above which the rate falls.

(c) Heating a soil for two hours at 80°C. or one hour at 100°C. eliminates its capacity to oxidise manganese.

(d) A number of biological poisons retard manganese oxidation.

It is possible in fact to discriminate between biological and non-biological oxidation of manganese in soils by means of a biological poison such as sodium azide, which does not affect the purely chemical oxidation. Non-biological oxidations of manganese take place to a marked extent only in alkaline soils such as those that have been highly limed. It is well known that soil contains organisms capable of oxidising bivalent manganese. This has been shown by Beijerinck, Gerretsen and Nachlan, but it was not known, until the present work was carried out, how far manganese oxidation in soil is accomplished by micro-organisms. The usual view in the past has been that manganese largely undergoes autoxidation in the soil; that is, that it changes spontaneously in the presence of air.

Not only is bivalent manganese oxidised to states of higher valency by soil micro-organisms, but similar agencies are partly responsible for the reduction of ter-and quadrivalent manganese to the bivalent form.

Many substances to be found in soil will reduce manganese dioxide, for example, polyphenols and sulphydryl compounds and ferrous ions. But living cells will accomplish the reduction in presence of traces of "carriers", such as pyocyanine, a pigment normally formed by *B. pyocyaneus*, a soil organism. Many bacteria in presence of certain organic substances, which they activate, reduce a molecule such as pyocyanine to its colourless leuco form, which in turn reduces manganese dioxide to its original form, manganous ions being produced. Thus the pigment acts as a reduction carrier between the organism and the manganese dioxide.

As might be expected from these facts, the addition of glucose and other carbohydrates to a soil containing manganese dioxide brings about an increased production of bivalent manganese ions, for the glucose stimulates the growth of organisms which, in presence of glucose and the natural carriers in the soil, reduce the higher valency states of manganese. This is shown in Figure 2, from which it is clear that the glucose perfusion of a soil increases bivalent

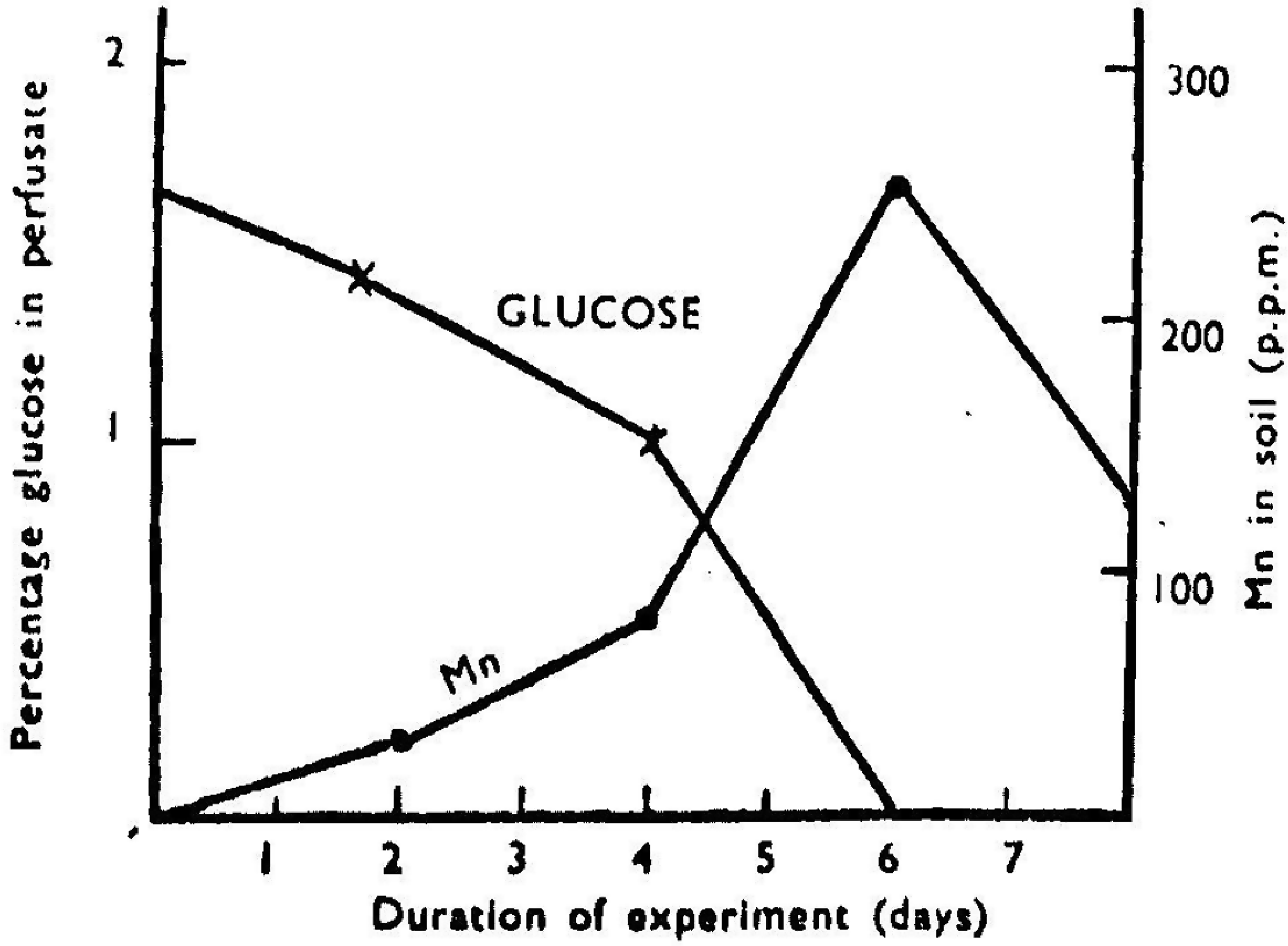


Figure 2

manganese concentration in proportion to the amount of glucose present. If the experiment is modified so as to decrease the moisture present, the effect of the glucose under aerobic conditions in stimulating bivalent manganese formation is not so apparent. This is simply due, however, to the experimental conditions favouring a relatively higher rate of biological manganese oxidation.

These facts point conclusively to the existence in soil of a cycle of biological changes involving manganese oxidation and reduction. The kinetics of this cycle determines the amount of bivalent manganese available in soil for plant nutrition at any moment.

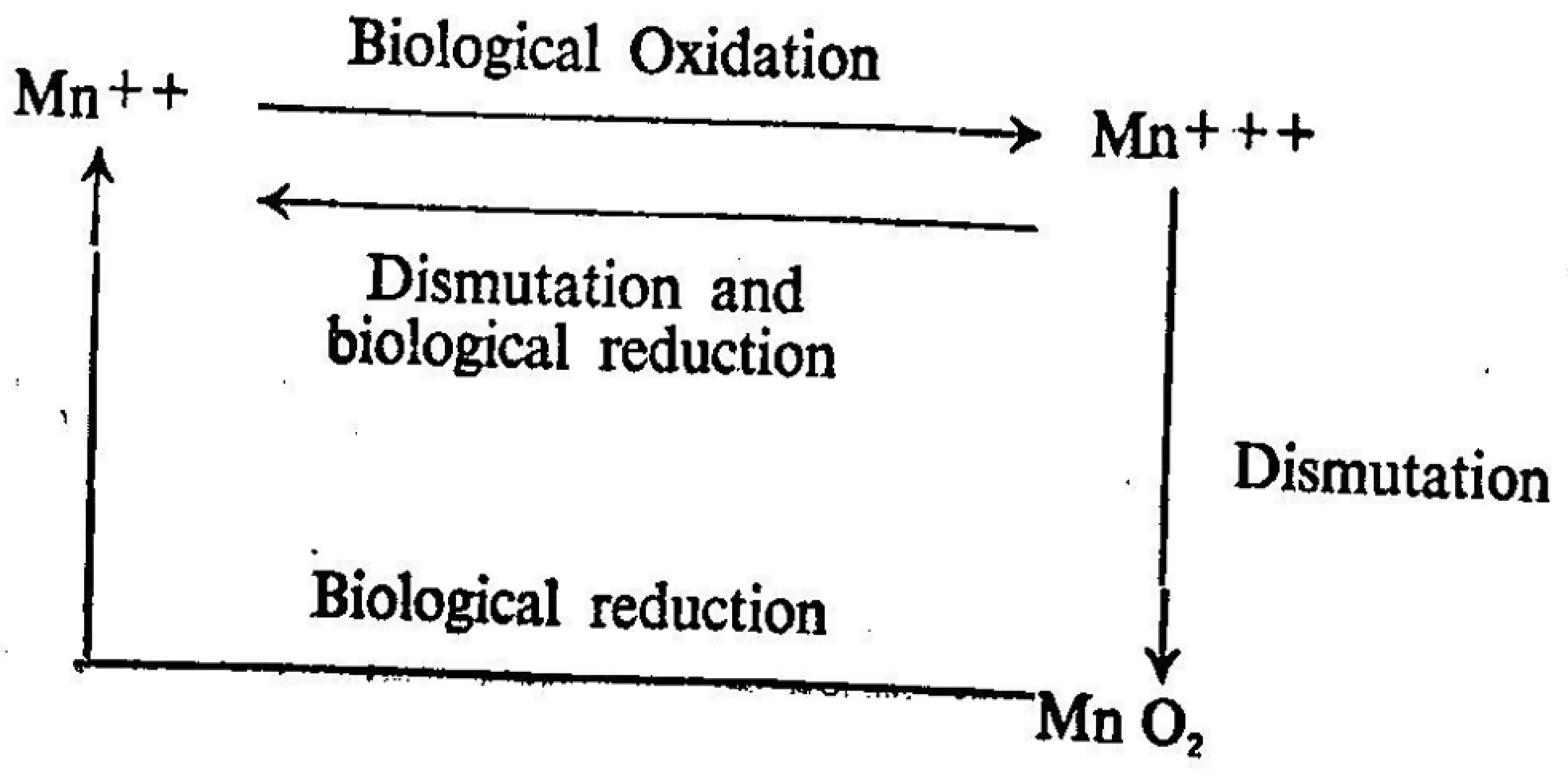
My colleagues, Dr. Mann and Dr. Dion, have shown that the first product of biological oxidation of bivalent manganese in soil is the tervalent ion ($Mn^{++} \longrightarrow Mn^{+++}$).

Meyer and Nerlich found in 1921 that manganic hydroxide, $Mn(OH)_3$, is stable in alkaline solution, but decomposes in acid solution to give a mixture of bivalent manganese and manganese dioxide, thus:

$$2\ Mn(OH)_3 = MnO + MnO_2 + 3\ H_2O$$

This dismutation goes on in soil; so that it is clear that, when biological oxidation of bivalent manganese takes place in neutral or slightly acid soils, tervalent manganese is formed and dismutes forming manganese dioxide and bivalent manganese which undergoes biological oxidation once more.

The manganese cycle in soil under aerobic conditions may be pictured as follows:



Under anaerobic conditions or in presence of a respiratory poison such as sodium azide, the equilibrium shifts markedly to the bivalent manganese side on the left and it will be expected that ultimately all the manganese will appear in that form.

Another factor that should also be considered is the immobilisation of manganese cations as insoluble manganese carbonate or as complexes in inorganic or organic materials.

In the complicated conditions occurring in the field, the equilibrium concentration of bivalent manganese will vary greatly according to the conditions that govern the bacterial population and its reducing or oxidising properties, *e.g.*, moisture, aeration, organic matter, temperature and hydrogen ion concentration.

It must be obvious that the manganese deficiency problem involves many factors bearing on the manganese cycle and will not be cleared up until much more work has been carried out on the kinetics of this cycle.

Carbon dioxide and soil metabolism

Let us turn now finally to a brief consideration of another molecule of great importance in soil metabolism—carbon dioxide. It is well known that the potentialities of the soil for the digestion or oxidation of organic compounds are immense. It may be regarded as the most effective digestive system known. Not only are cellulose, proteins and fats broken down in soil by a variety of organisms but more resistant materials such as lignins undergo change, probably into even more resistant substances such as humic acids. Clearly oxidation of the total carbon deposited on the soil by decaying plants and all forms of animal life must eventually take place, otherwise there would be a gradual accumulation of dead organic matter piling up on the earth's surface. The organic matter of a soil receiving no added material becomes gradually depleted as is shown by the fact that about 30 mg. of carbon dioxide may be produced per kilogram of soil of average fertility each day for about 200 days of the year. Formation of about seven tons of carbon dioxide for an acre of soil per year may take place.

The capacity of the soil to produce micro-organisms that will decompose organic matter seems to have no limitation. Organisms have been found capable of oxidising and utilising substances such as phenol (carbolic acid), benzene, toluene, xylene and many polyphenols. Gray and Thornton have found several kinds of bacteria that can oxidise the cresols, toluene and naphthalene. Keratin* is decomposed by strains of *Actinomycetes*. Johnson and his colleagues have isolated from the soil around a petrol-pump organisms which oxidise n-pentane, n-hexane, n-octane, n-nonane and attack lubricating and paraffin oils.

The amount of carbon dioxide evolved must be dependent on the respiration of the soil; it is derived partly from the activities of the micro-organisms present and partly from the metabolism of plant roots. The air of the soil is considerably richer in carbon dioxide than the normal atmosphere above, and the constant evolution of the gas by enriching the atmosphere at and above the soil level forms a definite stimulus to plant assimilation and growth. This is apparent from the work of Lundegaardh and many others. The formation of carbon dioxide is important also in bringing into solution relatively insoluble soil minerals containing phosphorus, potassium, calcium and magnesium.

Attention, however, should be drawn to the fact that carbon dioxide is important in the assimilatory activities of bacteria themselves. It yields the only form of carbon that can be utilised by the immensely important autotrophic organisms of soil. It plays an active part in the metabolism of heterotrophic organisms. (Autotrophs manage to exist on an inorganic source of nitrogen and carbon dioxide only; heterotrophs require their carbon in the form of organic matter. Wood and Werkman first pointed out that pyruvic acid, a substance occupying a key position in metabolic changes of the living cell, condenses with carbon dioxide in bacterial cells to form oxalo-acetic acid, which then undergoes a series of biochemical transformations. The carbon dioxide is thus brought into the assimilatory activities of the heterotrophic organisms responsible for this change. Using the stable isotope of Carbon C^{13} it has been found that the labelled carbon of carbon dioxide is present in the carboxyl groups of succinic acid synthesised by the bacteria.

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* The protein of hair, skin, hoof and horn.

$$CO_2 + HCH_2.CO.COOH \rightarrow HOOC.CH_2.CO.COOH.$$

The central position taken by pyruvic and oxalo-acetic acids in many metabolic changes occurring in bacteria and moulds implies that free carbon dioxide is assimilated by these organisms and is ultimately built up into their substance.

Wieringa showed that spore-forming organisms from mud, belonging to the *Clostridium* group, can convert carbon dioxide and molecular hydrogen quantitatively into acetic acid, an observation confirmed by Barker, Ruben and Beck, using the labelled carbon technique.

It is known that carbon dioxide can be reduced by certain organisms to methane, and an elegant experiment of Barker and his colleagues has shown that when the *Methanosarcina methanica* decomposes methyl alcohol in the presence of radio-active carbon dioxide, the resulting methane is radio-active. A part of the cell material obtained during the growth of a methane-producing organism is shown, by making use of radio-active carbon (in the carbon dioxide), to be derived from the carbon dioxide.

There are no observations yet on the possible part played by carbon dioxide of soil in the nutrition and development of heterotrophic organisms proliferating there, but it is clear from the facts given that it must be playing a highly important part in the general metabolic processes of soil.

It is not possible, in so brief an article, even to mention highly interesting aspects of sulphur, phosphorus, iron and hydrogen metabolism in the soil or to comment upon the valuable work being carried out on the elaboration of antibiotics by actinomycetes and fungi, which must greatly affect the biological equilibrium in soil. Nor can we write about the important symbiotic associations in soil, such as the mycorrhiza which offer such interesting biochemical problems. It must be clear that soil biochemistry is a wonderfully fertile field for investigations of the chemical interrelationships of micro-organisms and for the study of complex biological systems in every way as interesting as the more familiar cell systems of animal and plant tissues.

Medical Front

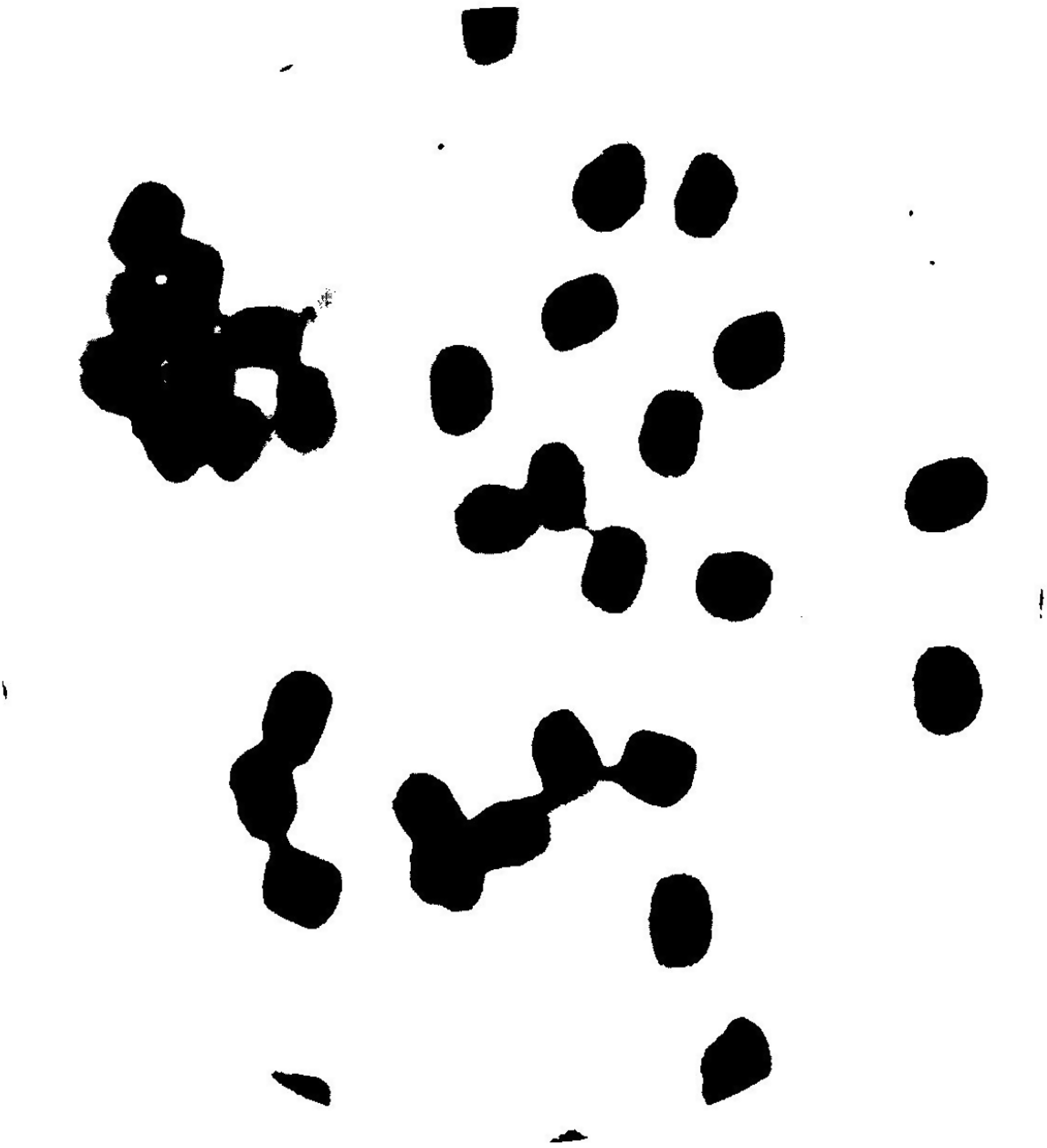
JOHN ENOGAT

The Common Cold

On another page (Plates 1–16) we show scenes from a unique experiment now being conducted at Harvard hospital, Salisbury, jointly by the Ministry of Health and the Medical Research Council, to investigate the nature of the common cold. It is a long-term experiment on batches of human volunteers, designed not to try out cold "cures", or even to find a cure, but to gain more scientific knowledge about this irritating and wasteful disease, which is reckoned to lose us forty million man-days of work annually. Only by slow, fundamental, painstaking work can we hope eventually to solve this problem: the cure will only become available when we know a great deal about the virus which is responsible.

Viruses are infectious germs, usually very much smaller than bacteria, from which they can be separated by filtration through collodion filters. They cannot be seen through ordinary microscopes, nor can they be grown in the tubes of broth or dishes of jelly on which the bacteria of diphtheria or scarlet fever or typhoid are cultivated in the hospital laboratory. They will only grow inside living cells; usually, that is to say, inside the common experimental animals (mice, rabbits, guinea pigs, ferrets, monkeys) and sometimes inside living eggs. This makes it more difficult to study them. In the case of the common cold virus the position is worse still since the only living thing where it will grow is apparently Man himself. All the laboratory animals are useless. Even eggs have so far not been successfully infected. One of the first tasks facing the Cold Research team at Salisbury and the National Institute for Medical Research, Hampstead, is to find something more

THE COMMON COLD



What a Virus looks like.

A portrait of the common cold virus is not available, and this is actually the germ of cow-pox, as used in vaccination against smallpox—quite a typical virus (magnified 35,000 times).

At Harvard Hospital, Salisbury, generously presented to Britain by Harvard University and the American Red Cross in 1941, at a cost of one million dollars, is now being conducted a research on the Common Cold. The investigation is unique in its scale, particularly in that ordinary people have volunteered in large numbers as experimental animals (see over).

1. Every second Wednesday, volunteers between the ages of 18 and 40 arrive in pairs at the hospital. For ten days each pair will live in isolation in a little hut, with a bedroom like this one.

2. But lunch on the first day is communal, so that the doctor-in-charge, the matron, and the administration officer, can explain the experiment, and the rules the volunteers must follow if it is to be a success.

3. They are asked not to have contact with any other human being apart from the medical staff. All their food is brought to them in thermos canisters left outside the hut door.

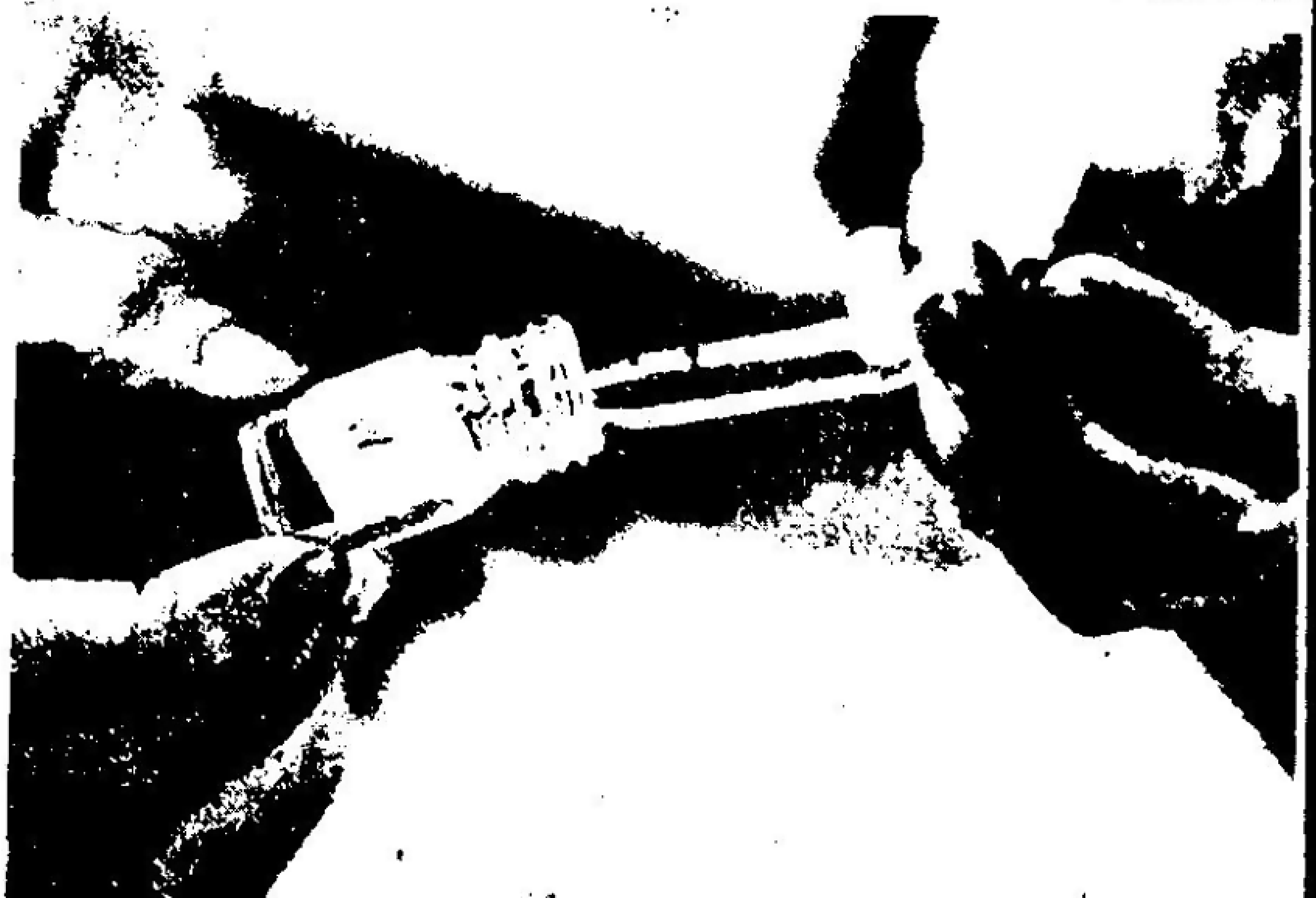
4. The huts themselves are comfortably furnished, provided with books, telephone, radio, and electric kettle.

5. Volunteers may go for walks in the grounds of the hospital, provided they keep at least thirty feet away from other couples and so avoid giving or receiving infection.

6. There is also a recreation hut which can be booked for table tennis. After each session, the bats and ball are disinfected and the whole hut aired for two hours before anyone else may go in.

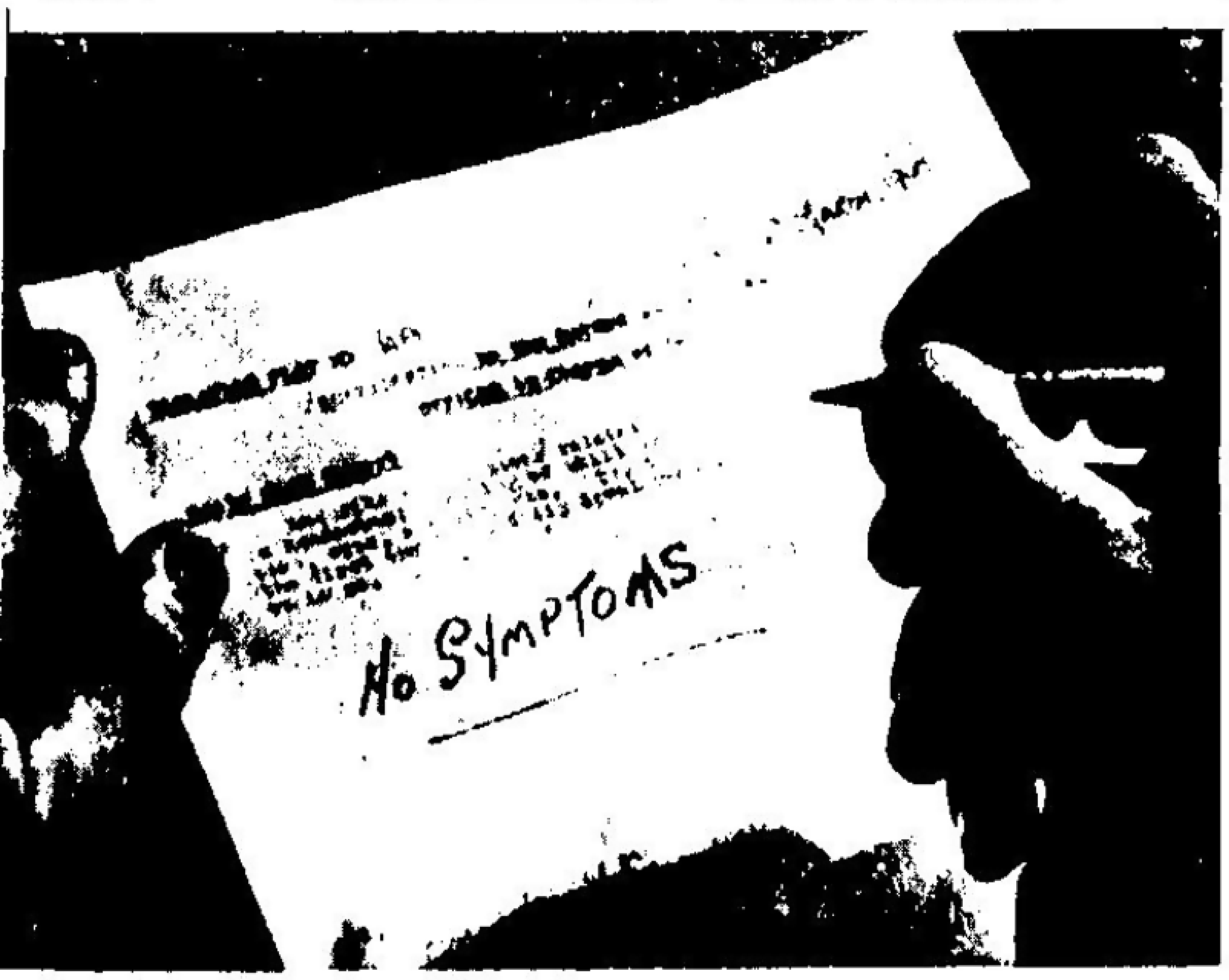
7. During the first three days the health of every volunteer is carefully checked, including a chest X-ray as shown here. Any "unofficial" cold, caught before coming to hospital, should declare itself in this time.

8. On the fourth day, the experiment proper begins. Some of the little bottles contain cold virus in their water, others do not, and only the researchers at Hampstead who packed them and sent them know which are which.



9. Each volunteer receives some of the contents of one bottle into the nose from a dropper.

10. Then the wait begins. Will the volunteer develop a cold? Every day the medical staff conduct a routine check-up.



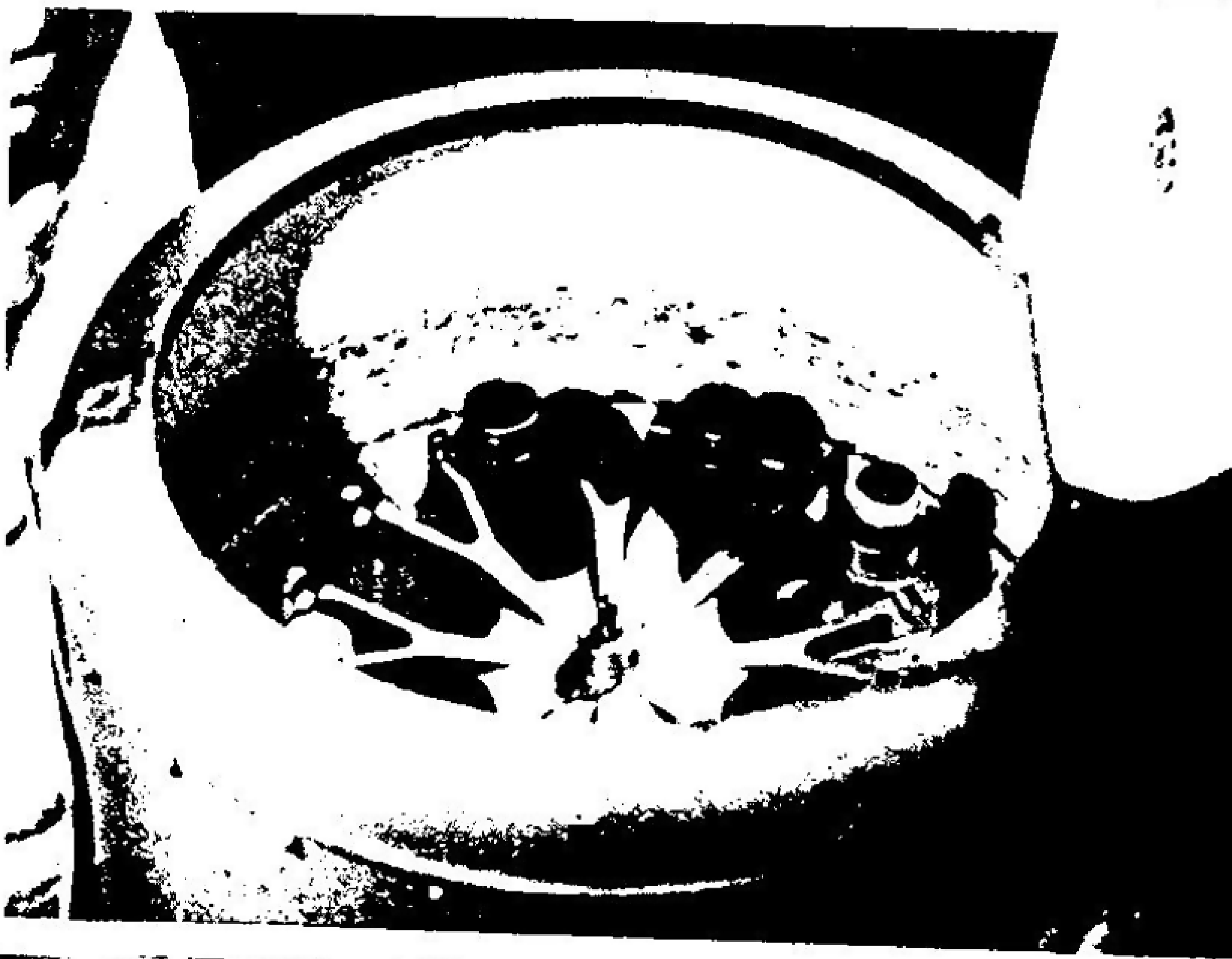
11. Every day, too, the " guinea-pig " writes his own report on himself.

12. Some of the " guinea-pigs " (about one-third of the total) get colds.

13. Their garglings and nose-blowings are collected and bottled, ready for dispatch to Hampstead.

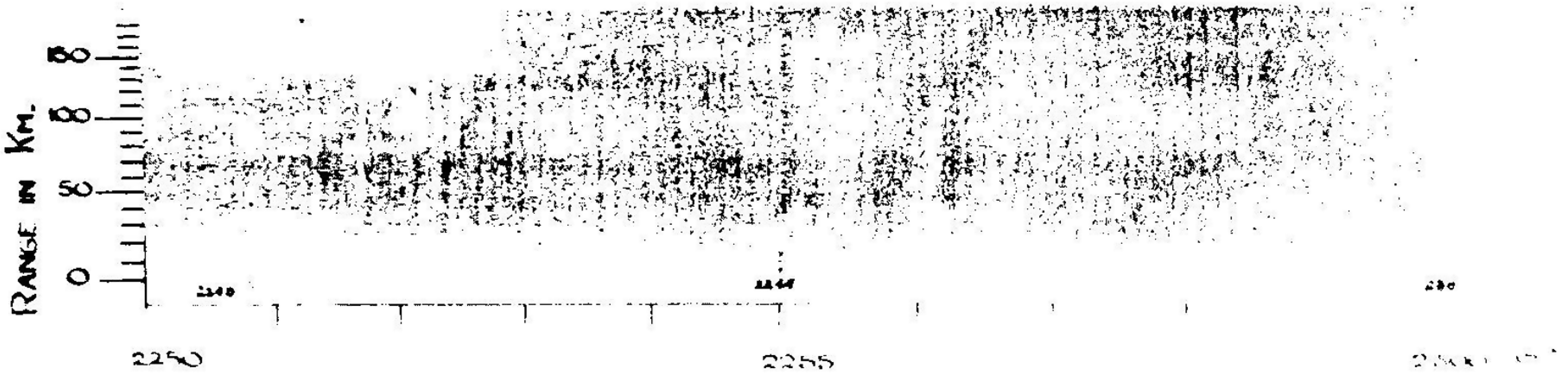
14. They are sent packed in dry-ice (solid carbon dioxide), to preserve them. Here Dr. C. H. Andrewes, F.R.S., leader of the research group, receives the parcel in his laboratory.

15. The specimens are whirled round in this centrifuge, so that all mucus and debris collect at the bottom of each bottle, and a clear liquid can be poured off.

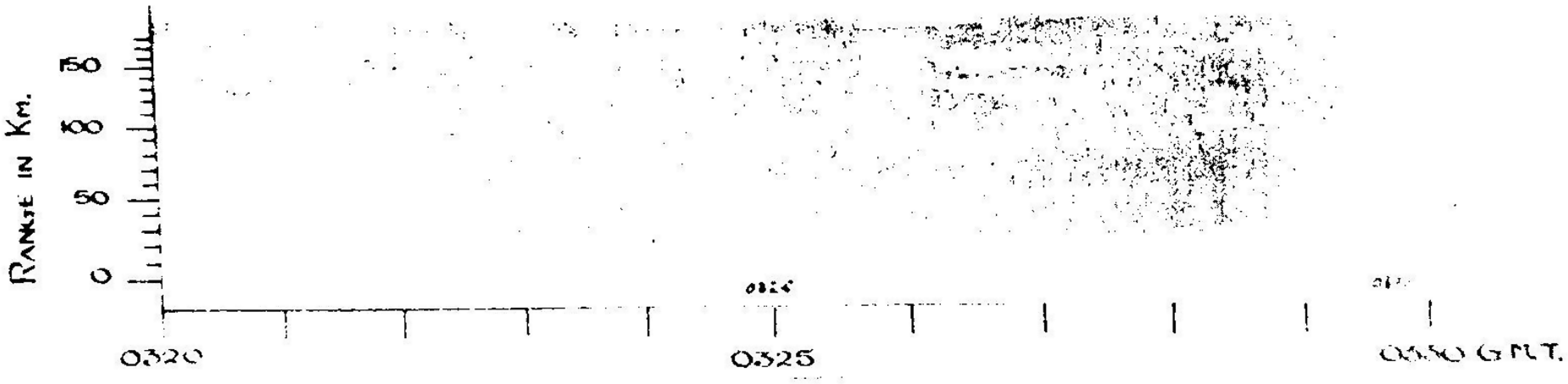


16. This liquid is then passed through a collodion filter of the type in the picture, which holds back all bacteria.

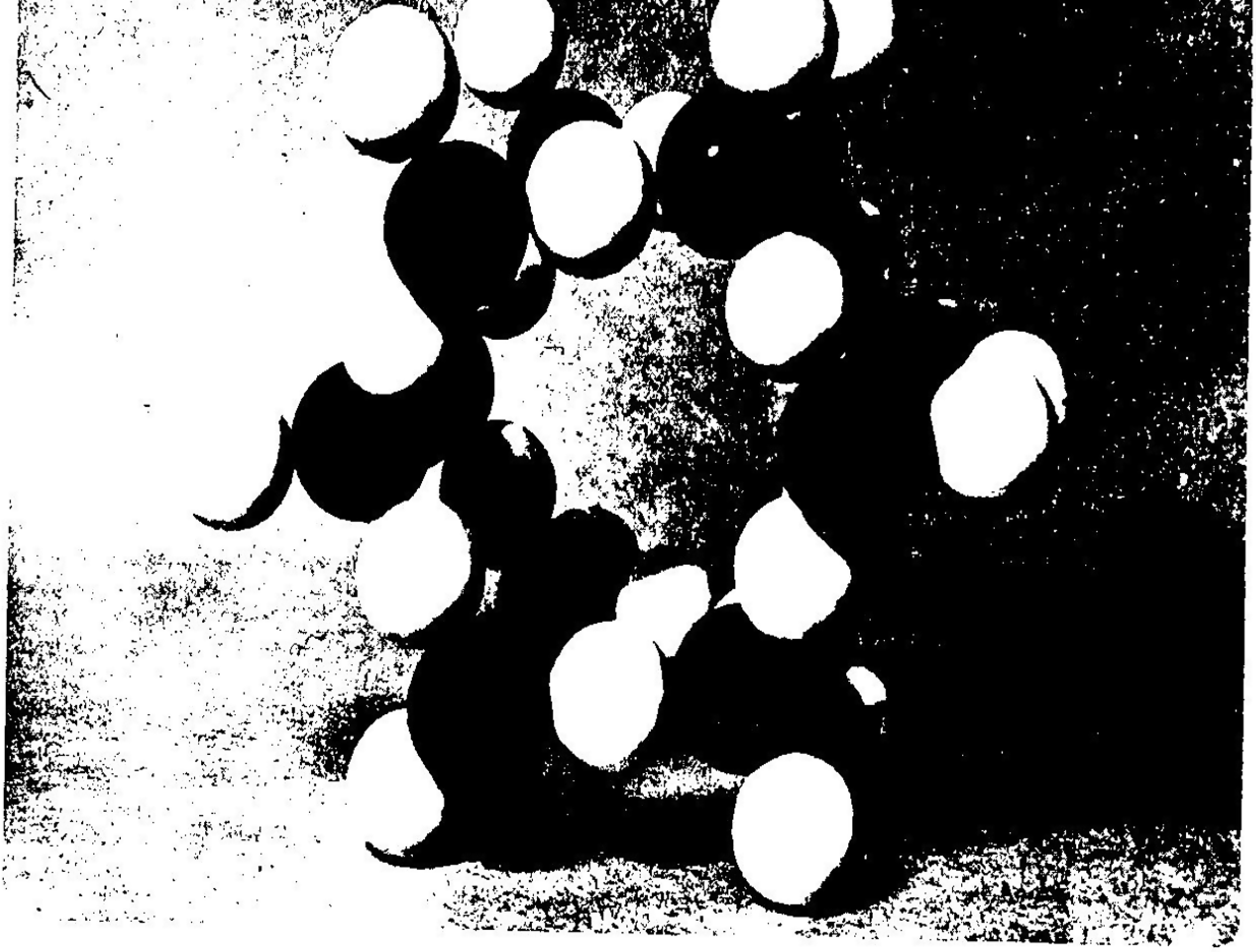
Now the laboratory research begins (see page 96). But for the volunteers the experiment is over, and they return home. Then the hospital cleans up ready to receive the next batch on Wednesday.



17. Ionisation trails recorded at Radio Research Station, Slough, on 9.10.46.



18. Ionisation trails associated with the Giacobini-Zinner Meteor shower on 10.10.46 and recorded at Radio Research Station, Slough. *See Meteors and Radar p.* 36.



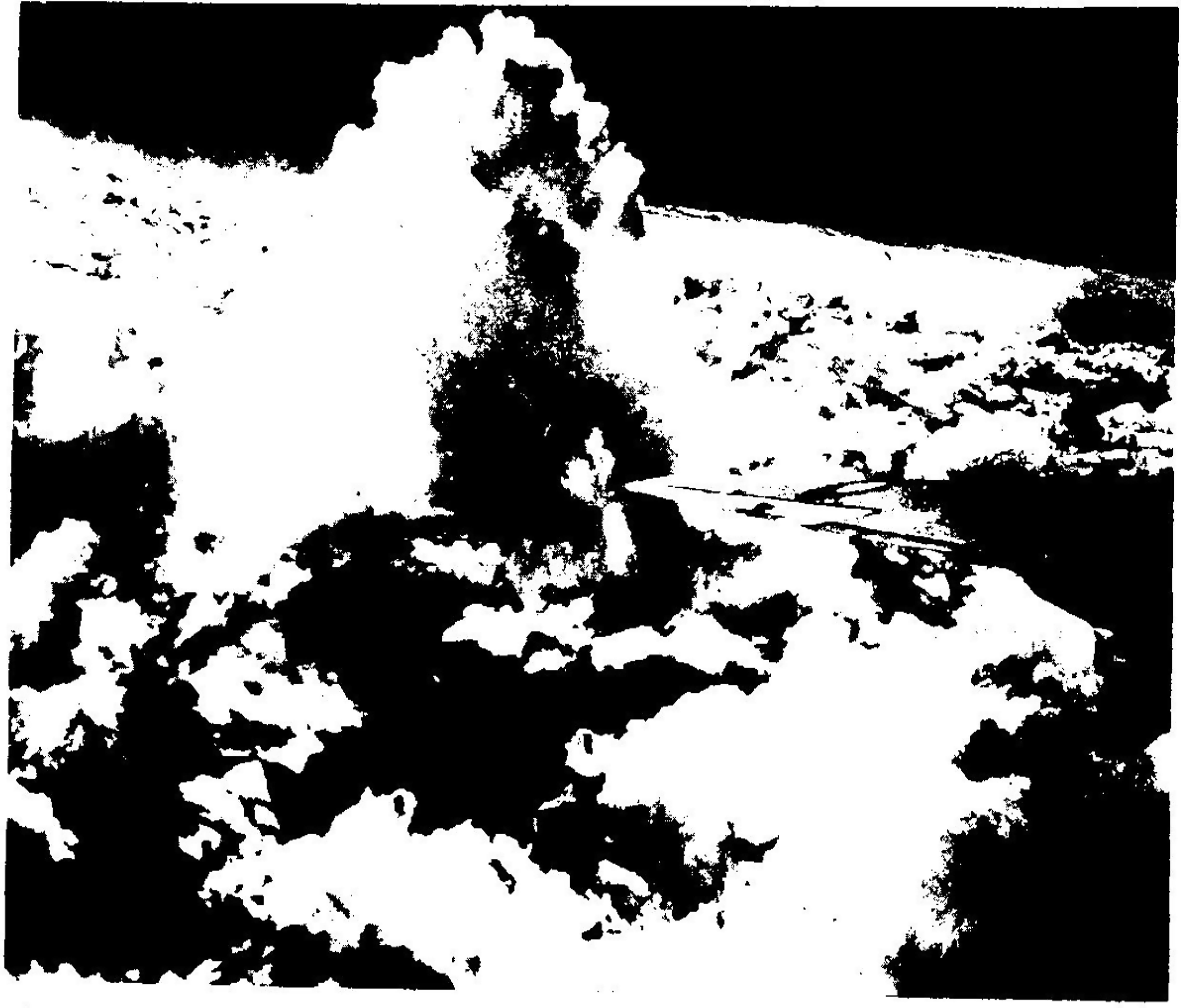
Plates 19-25 *illustrate Rain* (*p.* 104).

19. The structure of an ice crystal—black balls oxygen atoms, white balls hydrogen atoms.

20. Clouds over inland New South Wales on February 5th, 1947. The tops are about 22,500 feet and freezing level was 18,000 feet.

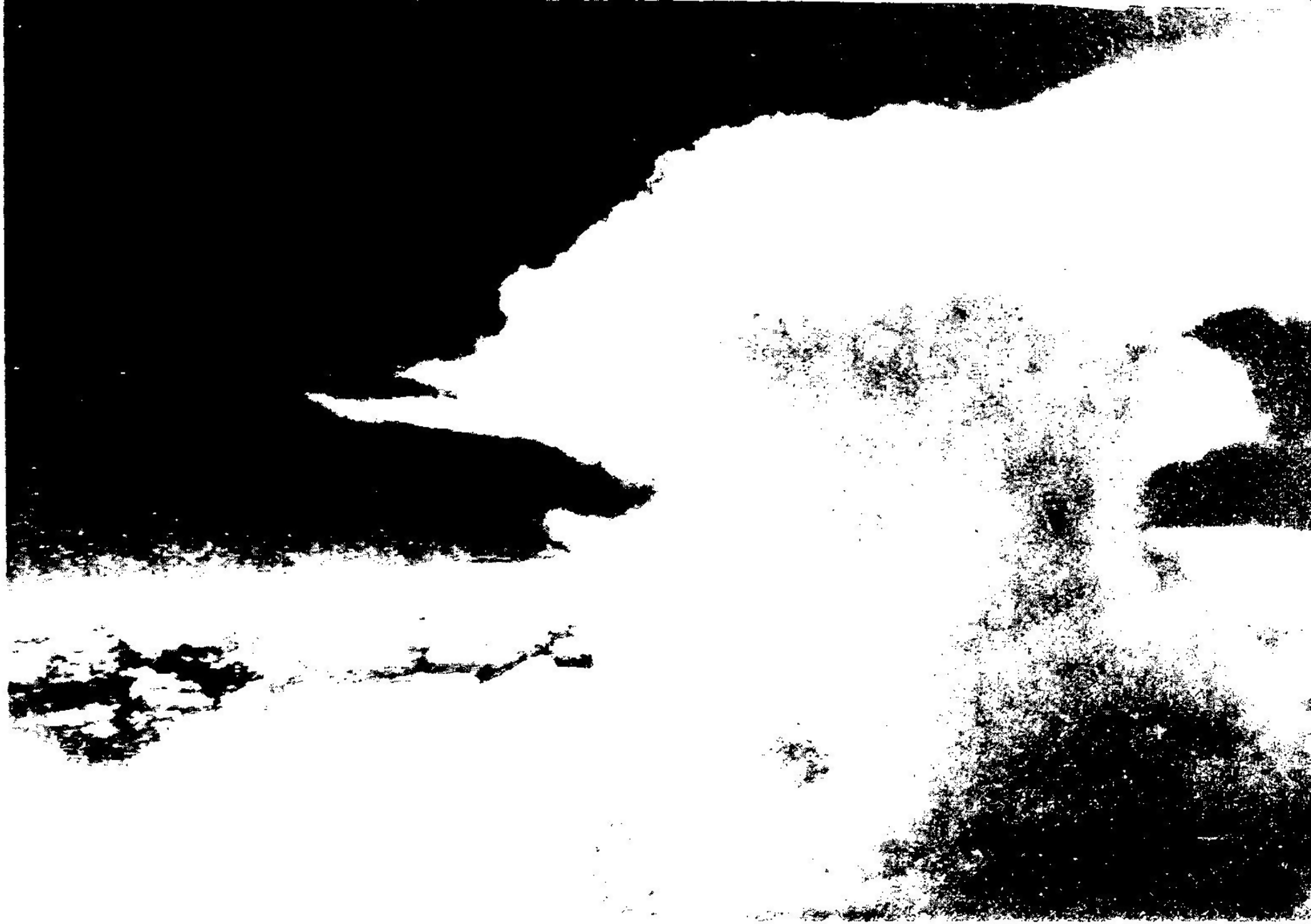
21. Over the sea the sky was clear.

22. Picture of a cloud, nine minutes after infection with dry ice.



23. Thirteen minutes after infection.

24. An anvil formed about twenty minutes after the dry ice had been dropped.



25. Final aspect of the infected cloud. Note the fact that the other clouds have not grown.

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Cave Science
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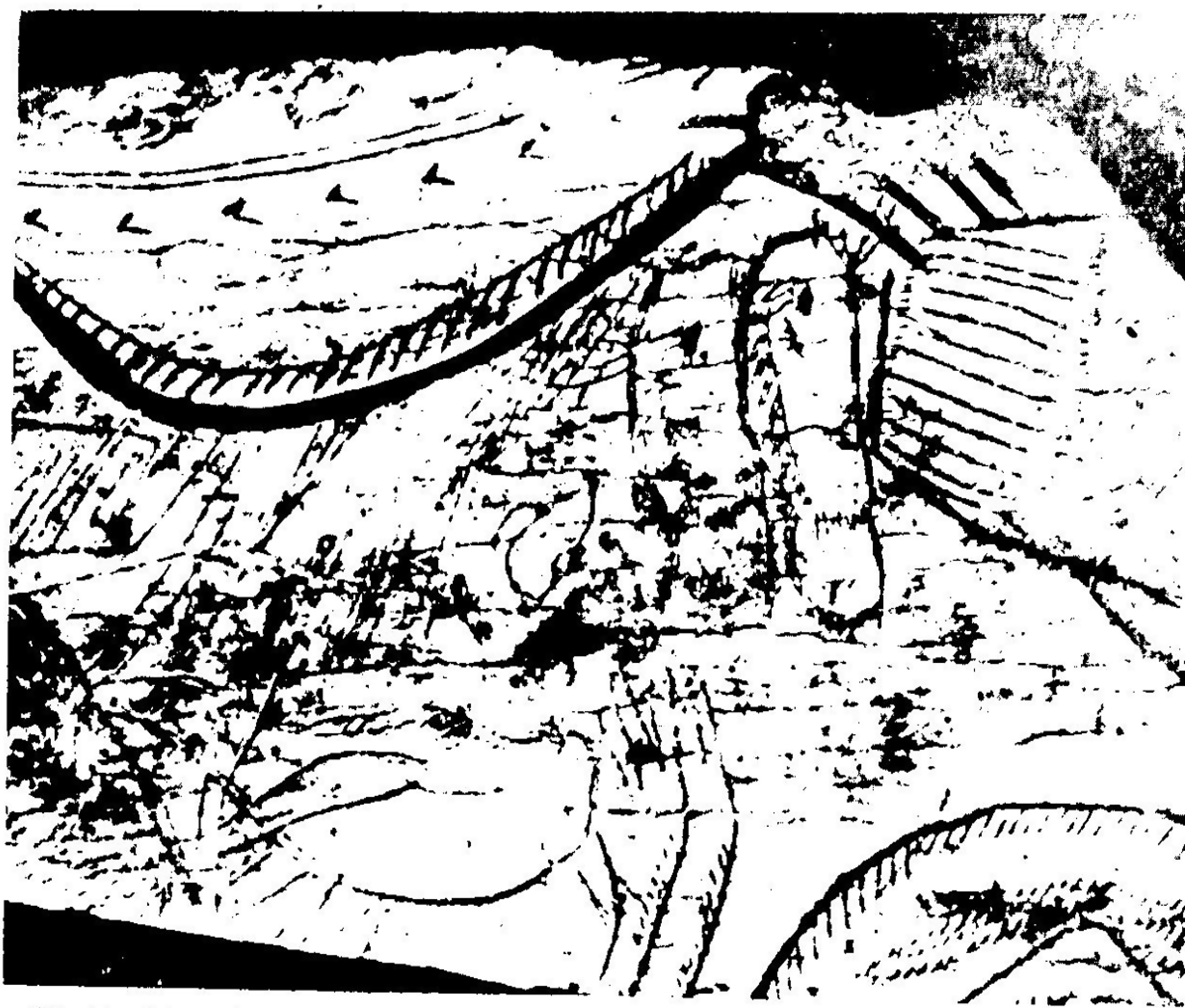
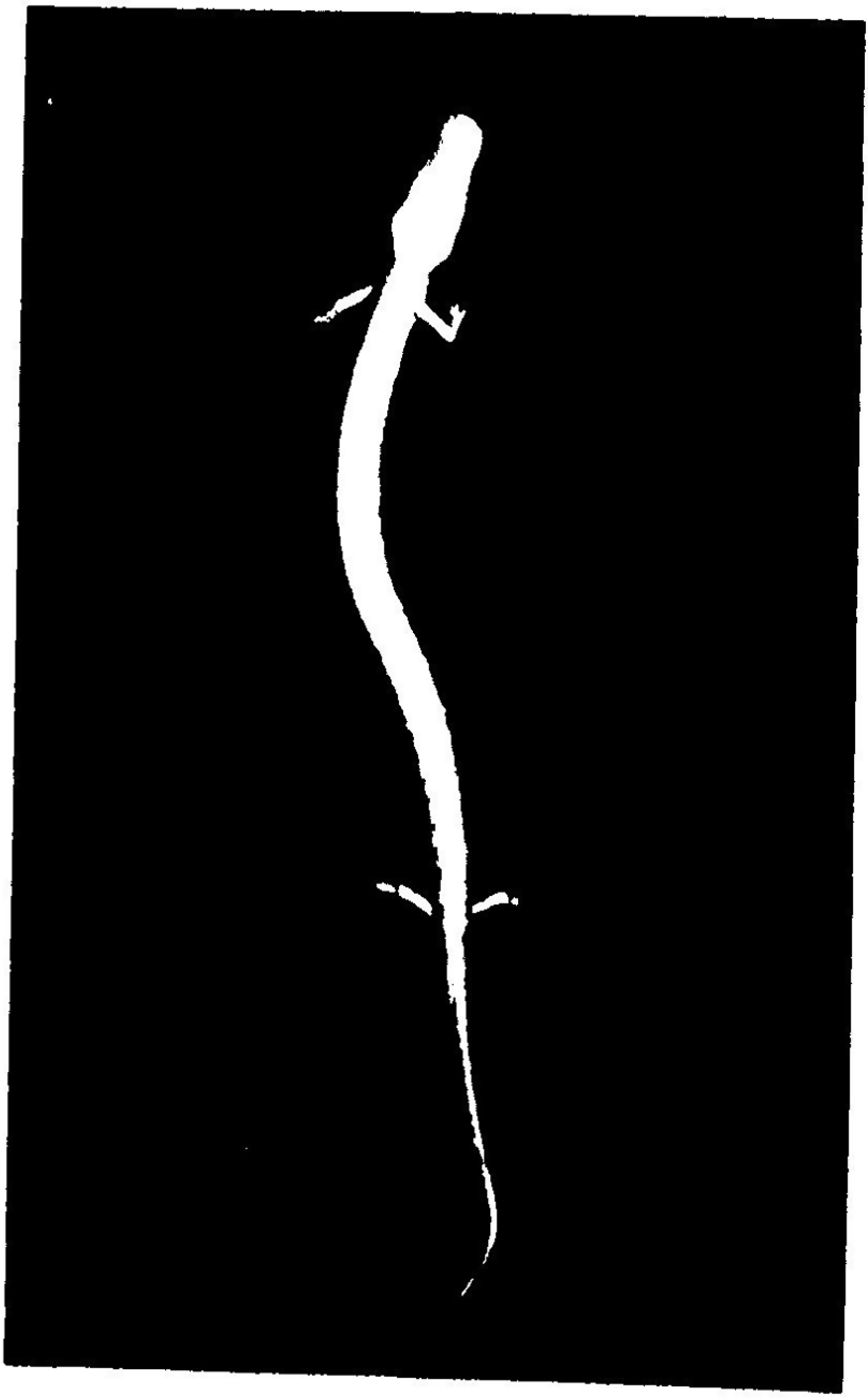
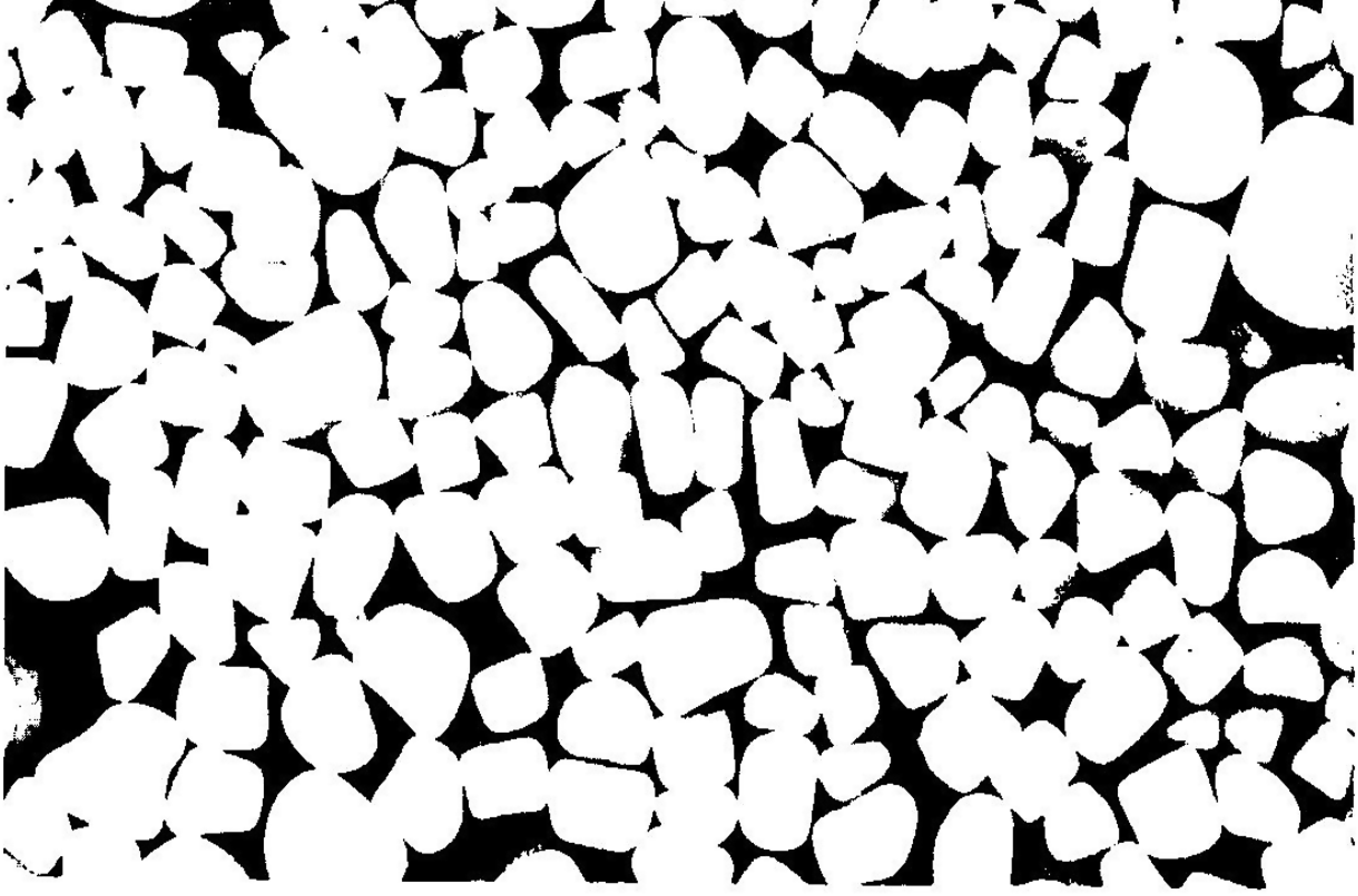
27. Descent into cave on a rope ladder.



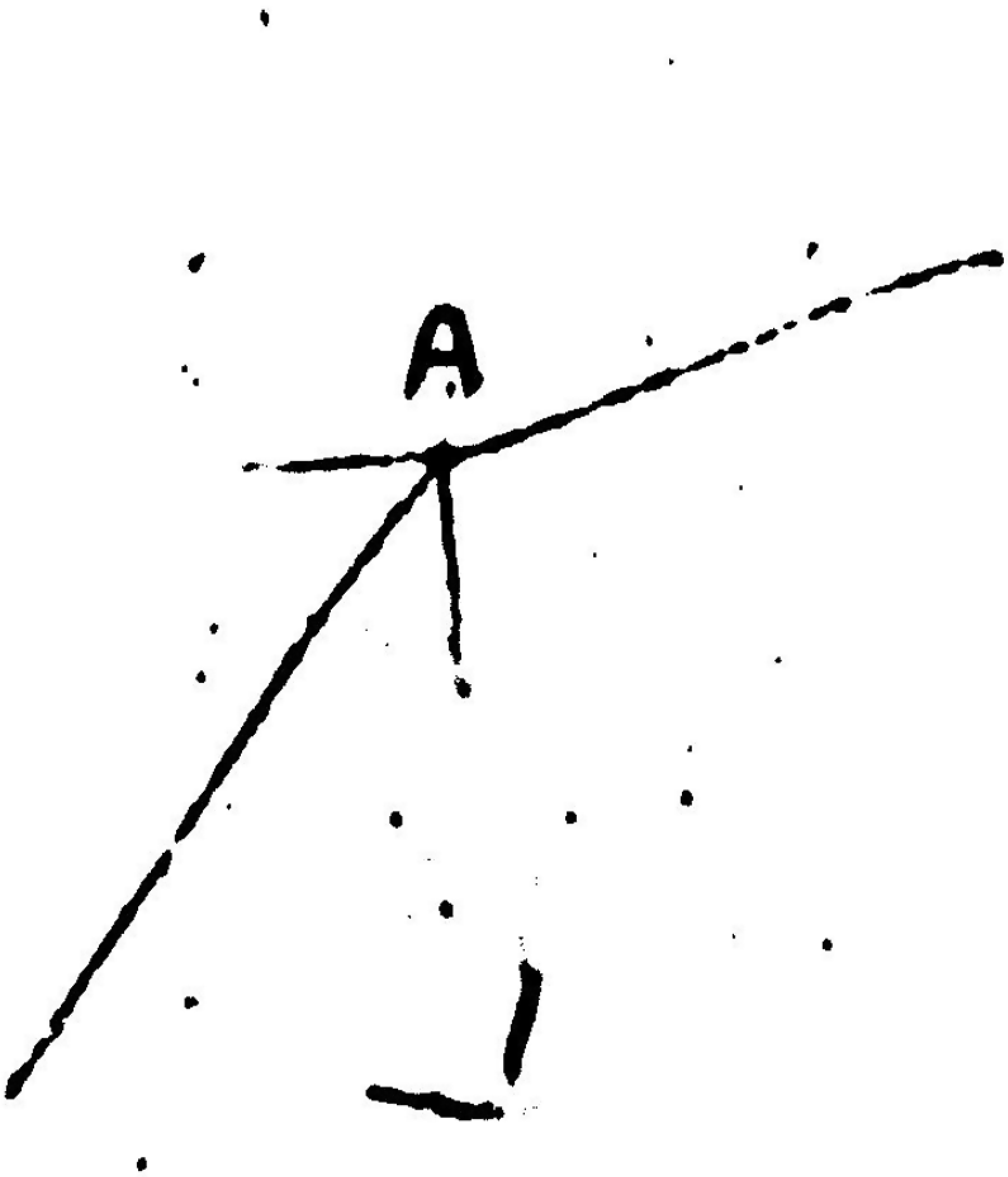
28. Prehistoric drawing of the Grasshopper Troglophilus on a piece of bone from the Grotte des Trois Frères in the Pyrenees.



29. A cavernicolous amphibian, Proteus anguineus *Laur*.

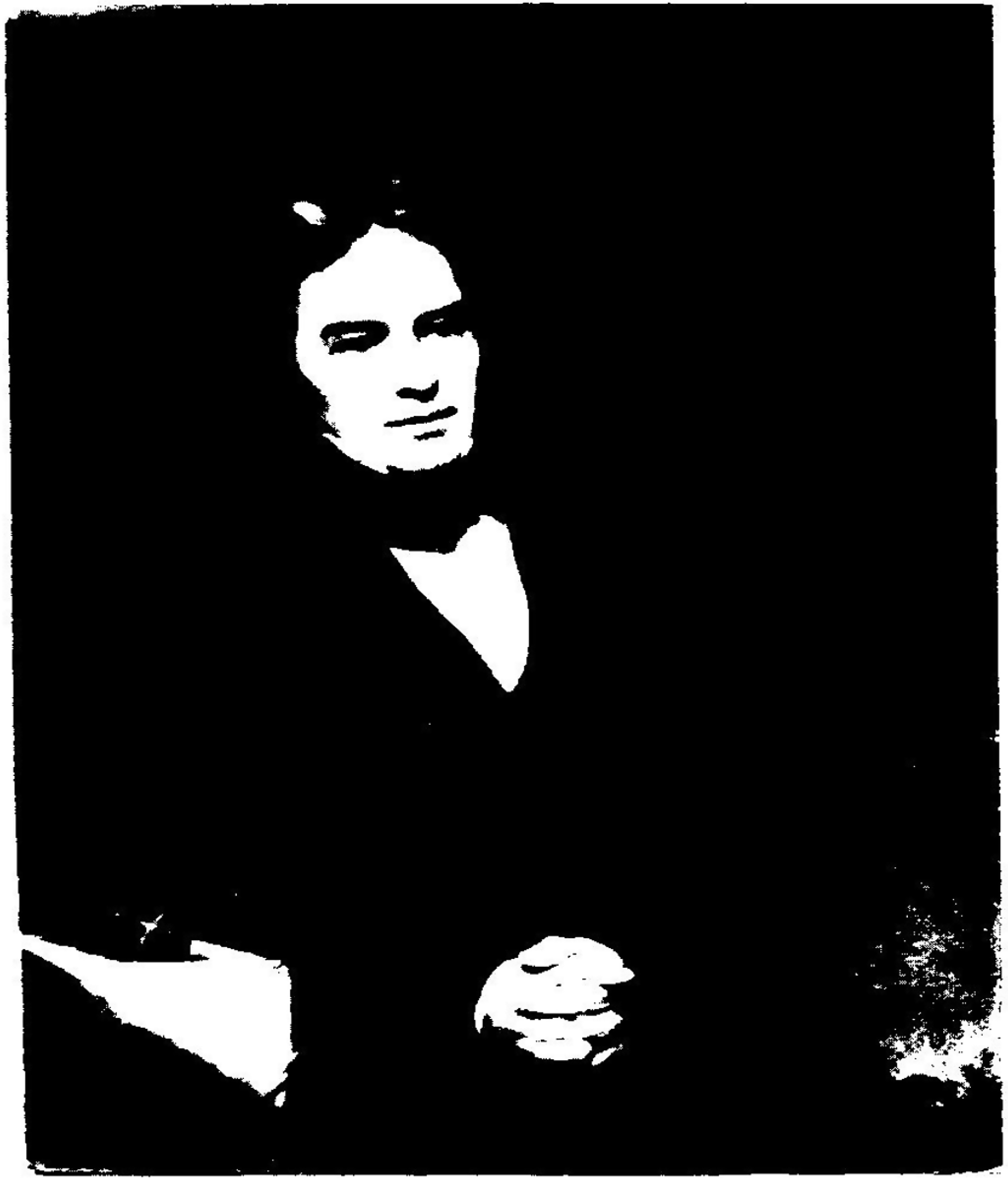


30. Concretions formed in underground water.

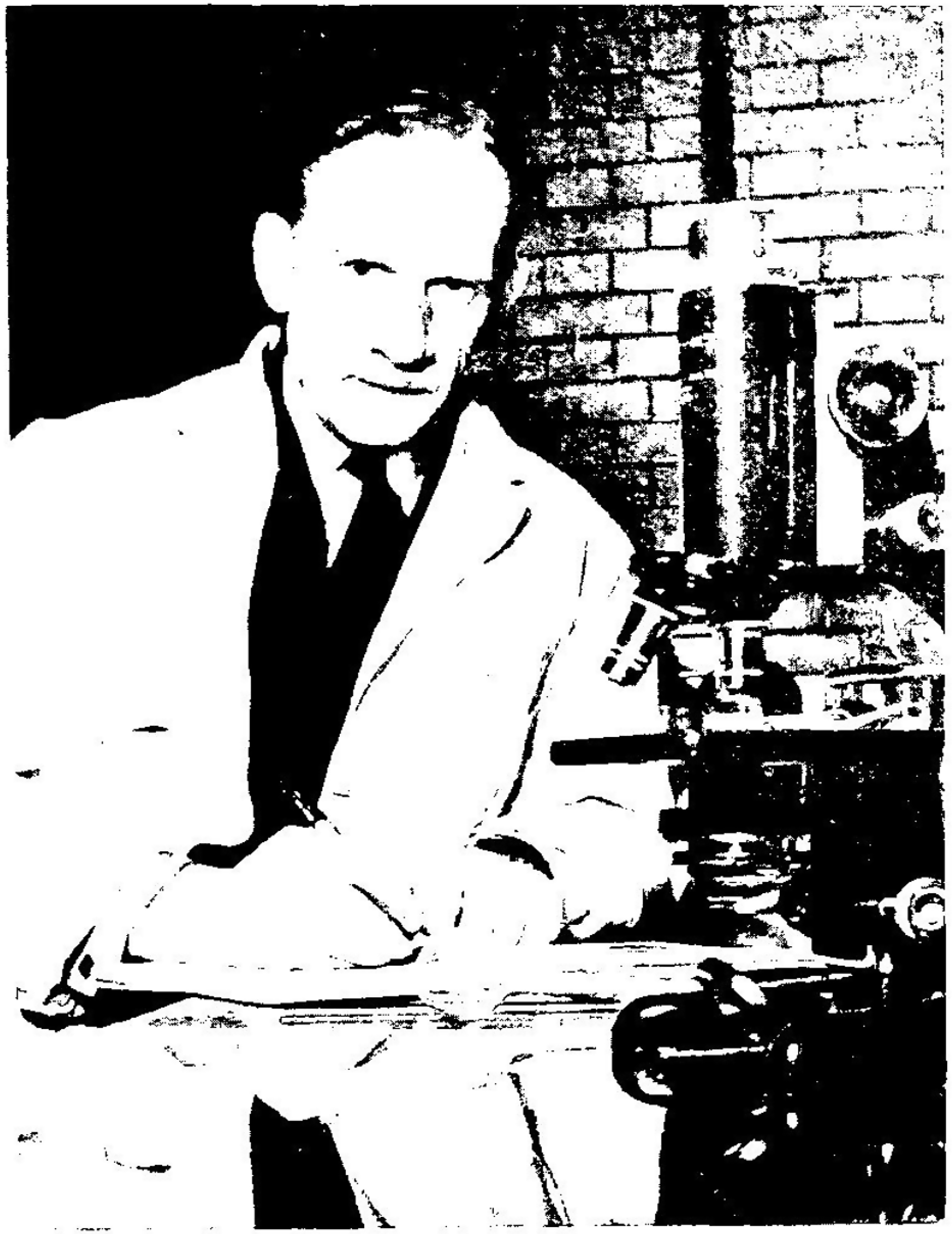


31. Atoms of the radioactive element thorium have been incorporated in the emulsion of a photographic plate. At A one of them has burst, giving off four alpha particles (helium nuclei) which have marked the emulsion in their passage. Two of the tracks look fuzzy because they are out of focus in this microphoto of the plate. *See page* 57.

32. Thomas Graham, first President of the Chemical Society, 1841–1843 and 1845–1847.



33. Michael Faraday.



34. Sir Robert Robinson.
President of the Royal Society

convenient than a human volunteer in which to grow the virus. A report put out by A. R. Dochez in 1931 that chimpanzees caught the cold has now been amply disproved, and so far the present team has apparently drawn a blank.

They reported a few of their results from the first ten months' work to the Royal Society of Medicine in May of this year. Throat and nose washings collected from people with colds on the first or second day of their illness were centrifuged to remove mucus and then filtered through collodion membranes in which the holes were on the average only seven-ten-thousandths of a millimetre in diameter. This is small enough to hold back all bacteria, but lets the virus through. The filtrate can then be used neat, or after various treatments, to infect volunteers. For instance it was diluted with water, and shown to be still infective when 100 times weaker than usual. It was stored at various temperatures and shown to be still infective after 3 days at 4° C, or after 27 days in a refrigerator at —10° C, or after more than four and a half months at —76° C. By doing further filtrations through membranes with still smaller holes, until one was found with pores too small to let even the virus through, an estimate of the size of the germ was obtained as something between 0.3 and 1.5 ten-thousandths of a millimetre across, a distance corresponding to about 200 atoms side by side.

On the more clinical medical side, the results show that most people go down with a cold on the second or third day after infection, while a few start in 24 hours or delay for almost a week. The cause of this variability is not known. An even more striking variability is shown in the liability of the volunteers to infection. Of 64 people receiving a dose of the germ, no less than 25 (about three-eighths) failed to catch cold at all, and a further 11 only had mild or very doubtful colds, so that less than half of them were really susceptible. This immunity apparently bore no relation to colds in the previous six months, for some volunteers in the immune groups of 25 had had them then, and some had not. If we only knew the nature of this immunity we might be able to stimulate people's resistance and ward off colds altogether. In spite of patent medicine advertisements to the contrary this cannot yet be done, and it is still a matter for research.

Penicillin and the sulphonamides are useless against colds, and in fact no drugs are yet known to fight any virus infection. The difficulty perhaps arises from the germ's position inside the living cell, where drugs cannot enter, or if they do, only at the cost of killing the patient as well as the disease. In 1943 there was a report that a substance produced by a mould, penicillium patulum, and called patulin had proved powerful in treating colds. Further tests on more people showed no significant improvement, however, and tests of this kind are difficult to carry out for a disease which usually only lasts a few days anyhow. It means very careful statistical comparison of treated and untreated patients, and when this was done on large numbers, patulin failed.

Without Comment

According to Mr. Glenvil Hall, Britain will spend sixty-eight million pounds of the taxpayers' money on scientific research in the year 1947-8. This will be divided up for the different sciences broadly in the following way:

Medical research	£698,000	(1% of the total)
Agriculture and fisheries	£2,070,000	
Industrial research ..	£14,780,000	
Military research	£49,731,000	(73% of the total)

Flesh on Fire?

A cut which gets infected becomes red, hot, painful, and swollen; a boil is a similar infected swelling. How do you regard this? Is the inflammation caused by the germs at work, and should the doctor's aim to be to suppress the signs of enemy infiltration? Or is the inflammation a manifestation of a vigorous body fighting back, and therefore to be encouraged and promoted? During the centuries medical opinion has swung back and forth from one view to the other. Before bacteria were known, inflammation in illness was welcomed as a sign of the strong patient. Plenty of pus oozing from a wound was a laudable state of affairs, just what the surgeon wanted to see, because experience had taught him (in the old days before antiseptics and penicillin) that the weak and old who showed little signs of inflammation usually soon died. Or if this did not happen the patient was found to stay ill for a long time, with recurrent fever, and slow wasting, while pus accumulated somewhere, dammed up and unable to escape in the usual way from a wound. So a steady flow of the sticky greenish or yellowish white fluid showed the situation was under control.

Then with the realisation that bacteria caused diseases, and the invention of antiseptics, and an aseptic technique in surgery, pus became a sign of invading germs, something to be stamped upon and cleared out, sometimes an indication of bad operational skill, always anathema. And so medical opinion swung the other way, and pus was laudable no more.

Now we are entering an altogether new phase in opinion on inflammation, a return to the older view that inflammation is a natural reaction of a healthy body, and as such to be approved and encouraged, but a view based on a great deal more knowledge than any hitherto, and therefore held with much more understanding and with diminished prejudice. In the first place the experimenters have taught us that all sorts of things injected under the skin and into the tissues will cause inflammation and that this is therefore not synonymous with infection. Dead germs do as well as the living, bits of metal and other foreign bodies, turpentine, "foreign" proteins, all bring about a similar change, which is not merely visibly the same to the naked eye, but even indistinguishable under the microscope. The small blood vessels in the neighbourhood of the infection open wide and admit a rush of warm blood from the deeper tissues—hence the visible redness and warmth. At the same time the blood vessels become more permeable and let fluid and blood protein, containing antibodies, through their walls, and this causes swelling. Also white cells from the blood are attracted to the inflamed part, and the bone marrow which makes these white cells steps up production.

All these changes follow the stimulus to inflammation, whether germ or other foreigner. How and why ? Professor Valy Menkin of Philadelphia has for some years been putting forward heterodox ideas on the subject, and now at last they are gaining some ground. He argues that the germ, the piece of metal, the turpentine, or other inflammation-starter, acts by damaging the skin it reaches, and this skin then gives off a number of chemical substances which make the blood vessels open, the swelling appear, the white cells migrate. Some of these substances he can extract from normal skin, and when injected again they produce some of the symptoms of inflammation. Leucotaxin attracts the white cells, leucopoetin stimulates the phagocytes, and so on. These substances still need a great deal of study by chemists. But the underlying idea is fruitful and probably sound. Inflammation is a complex natural bodily reaction, carried out through the agency of hormones. On its efficiency depends part of your natural resistance to infection, and the more that is learnt about this subject, the greater the hope of ultimately preventing all illness.

Dangerous Work

For some time now, research has been going on into a disease of newborn lambs called swayback (see an earlier report in *Science News* 3, page 52). This degeneration of the lamb's nervous system, leading to various kinds of paralyses, is prevented by adding a little copper sulphate to the diet. Now comes a startling medical report that out of eight research workers in a group studying sway-back two or three years ago, four have since gone down with a nervous disease, disseminated sclerosis. This is ordinarily not a very common disease, so that it is startling to find 50% of the research group affected. In it, patches of degeneration of nerve fibres occur scattered throughout the spinal cord and brain, the patches slowly increasing in number as the years pass; and the symptoms produced are chiefly those of a creeping paralysis. Hitherto disseminated sclerosis has been regarded as a non-infectious disease of unknown cause and rather ineffective treatment. Mostly it went its own capricious course in spite of the doctors, and medical scientists were blank as to how to begin to investigate it, to improve this unsatisfactory situation. It seemed likely that the lead to a solution of the problems would come, as so often, from some quite other and unrelated branch of science.

Perhaps that is what has happened now. Perhaps a relation between swayback and disseminated sclerosis will be revealed, and this chance observation on the unfortunate scientists is no more than a straw in a possible wind.

Incidentally there is another aspect to the matter. Up to now there has been a great divorce between medical research and investigation of animal health. Yet fundamentally both sciences are aimed at the solution of similar problems, and it is to be hoped that the linking together of swayback and disseminated sclerosis is only the beginning of a closer collaboration between veterinary scientists and the doctors.

Jaundice

People turn yellow in sickness from various causes, and jaundice is therefore not a disease but a symptom. Sometimes it is a sign of sudden blood destruction, as when malarial parasites wreck the red cells on a large scale, and the sudden rush of decomposing red pigment stains the skin and eyeballs. More often it is the result of a blockage of the bile duct, or of damage to the liver itself.

One form of liver damage, to which considerable attention has been paid recently, is an infectious sort (therefore known as infectious jaundice or hepatitis) which occurred in epidemics in the armies in North Africa and the Middle East. It is apparently a virus infection (like the common cold), spread from person to person by direct contact and perhaps also by poorly washed cups and spoons or by flies, walking over food after buzzing round latrines.

In studying this particular disease, some of the most valuable information has come from doctors in country districts, where people live few and far between, and do not travel about very much. When the spread of Infective Jaundice through a population of this kind is followed, it becomes possible to time the contacts of the well and sick exactly, to say how long after infection a person lives before the yellowness appears (the incubation period is found to be one month), and during which stages of the infection such a person is himself infective. In fact in general, country practitioners are very well placed for studying the natural history of illnesses.

But when it comes to answering the question what the virus is doing in the body during the silent month before jaundice appears, or what is the best treatment, we must turn to the hospital and laboratory scientists. Treatment at present is confined to helping the liver in its convalescent period with plenty of protein (meat) food, and in particular with an aminoacid component of protein which contains sulphur, and is called methionine. Experiments on rats with livers damaged by arsenic or chloroform poisoning, or by very poor quality diets, such as the normal food of the Bantu native African, have shown that methionine in the food protects the liver to some extent. Fewer rats succumb to the poor food or the poisoning, more recover if already poisoned. It is not yet proved that this result applies also to humans. But doctors have no right to wait. They must start any possible treatment as soon as it is thought of, and leave the scientists trailing along behind assessing and modifying in the light of further experience. At present, it is only fair to report the methionine treatment as not proven.

Rain

ERIC KRAUS

IN 1945 and 1946 an unremitting drought struck the North-Western districts of New South Wales. The pastures dried to dust, and the large flocks perished as weeks and months passed by without life-giving rain. Yet on many an afternoon dark heavy clouds built up into the sky, only to vanish again mockingly in the evening Where did these clouds come from? Why did they not rain? Could human ingenuity devise a method which might force them to yield their water? Recent studies allow us to give a fairly plausible answer to such questions.

Prologue

The molecules of any substance carry on an eternal dance. In a crystal they oscillate about their stations in the crystal grid; in a gas they rush hither and thither through space, colliding with each other all the time. The intensity of the molecular dance depends on the temperature. As a matter of fact, temperature may be defined as a quantity which is proportional to the mean kinetic energy of the molecules. The kinetic energy of any moving object—be it a molecule, a motor car or a planet—is given by half its mass multiplied by the square of its speed.

In a mixture of gases, the mean kinetic energy of the individual component molecules will be equal. The reason for this is easy to understand. When a big, heavy molecule hits a lighter one it will send the little fellow flying, just like a bulky footballer who collides with a frailer opponent. A little molecule hitting a big one, on the other hand, will make as little impression as a pebble thrown against a rock. This causes the heavy molecules to move in the mean less fast than the lighter ones.

When the earth was young, its atmosphere probably contained much hydrogen. Unlike the sun, and the larger of her sister planets, our small globe had not enough gravitational pull to retain the light and therefore fast-moving hydrogen molecules. Within a few thousand years most of them must have dispersed, shooting out into space like very fast rockets. The remainder combined with oxygen to form water vapour. As the atmosphere cooled further, the water vapour began to condense, perhaps at first only on the night-shaded side of the earth. Gradually the patches of condensed water spread. When they became permanent the first ocean was born.

Molecular Forces

When we lift a stone, we have to work against the force of gravity. The physicist says that this work is used to increase the potential energy of the lifted object. When the stone drops again, the potential energy which we have put into it is changed into the kinetic energy of the fall. Finally on striking the ground, the latter is converted into the energy of molecular oscillations, in other words, into heat, which is conducted away by the soil and the air.

Molecules too, as stars and planets, attract each other at relatively large distances. Yet when they are brought very near together a repellent force becomes predominant, which tends to drive them apart again. The potential energy associated with these forces is shown in Figure 3. We can compare this figure to the section across the surface of a valley. On the right side is a kind of plateau, where the potential energy alters little with distance. This means that the molecules exert no forces upon each other when they are fairly far apart. If we lessen the distance, the attractive forces come into play. The potential energy of molecules which move towards each other, now decreases like that of a stone which rolls down into a valley. At D in the valley bottom, a minimum of the potential energy is reached. In order to come still nearer together, the molecules would have to be pushed up the steep slope of the repellent forces.

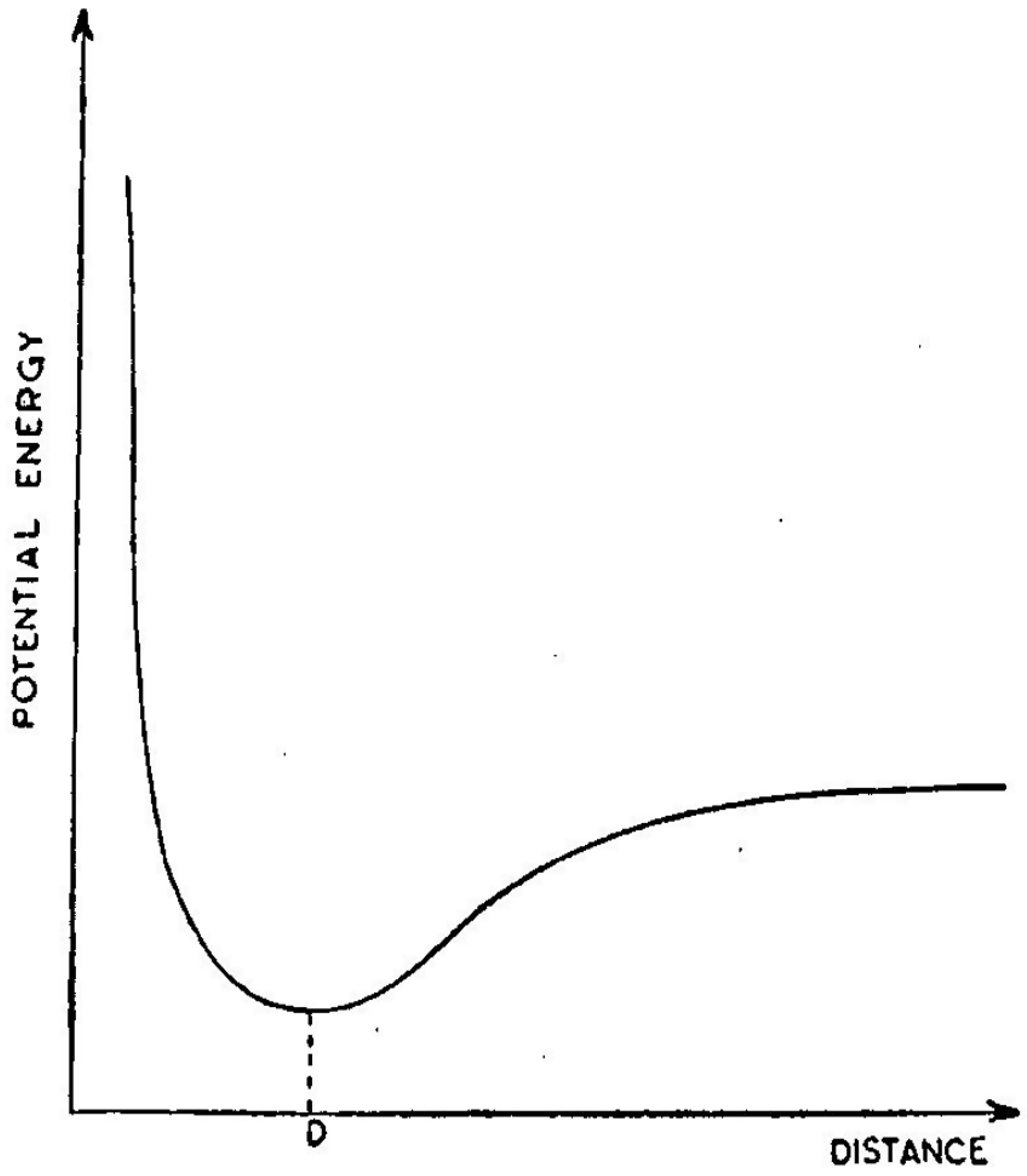


Figure 3

The attractive and the repellent forces balance each other at D. This corresponds to the distance between the molecules in their solid or liquid 'phase'. The actual length depends of course on the substance. The plateau on the right where the forces vanish again characterises the molecular distance of the gaseous or vapour phase.

Down in the valley at D, the molecules of solids and liquids rock left and right in their thermal dance. Every now and then, one gets an impulse which carries it right out of the potential valley on to the high plateau of the vapour state. It is then said to evaporate. Obviously those jerky molecules which overcome the bonds of attraction, and roll out over the brow of the potential slope, will be just those which oscillated most vigorously and had therefore much kinetic energy even in the liquid phase. The mean of the molecular kinetic energy is continuously lowered by this escape of the fastest molecules, that is to say, a liquid is cooled by evaporation. The opposite happens when a fast vapour molecule hits the surface of a liquid. The impact will rock all the surrounding liquid molecules, and the increased kinetic energy of their thermal dance will make itself felt as increased heat—the so-called heat of condensation.

Water Vapour in the Atmosphere

There are always some vapour molecules over every liquid surface. Occasionally they will fall in and condense, whilst others take their place by evaporation. If the number of those reaching the liquid from the vapour is equal to those leaving the liquid we say that the vapour is saturated, or in equilibrium with its liquid.

The heating of water increases the violence of the thermal dance, and thus enables more molecules to escape from the potential valley of the liquid state. A vapour which is to be in equilibrium with warm water must therefore contain more molecules than one which is saturated relative to a colder surface. The saturation pressure increases accordingly with the temperature.

Cold air can contain but few vapour molecules. When it moves over a warm ocean, the number of molecules which it receives from below becomes much larger than the number of those which fall back. The moisture content of the air must thus increase. Enormous quantities of water vapour are supplied in this way to the icy winter winds of Canada and Siberia, when they flow out over the Gulf Stream or the warm currents of the North Pacific. Much vapour also reaches the atmosphere in the fresh trade winds in their passage over lukewarm tropical seas. In addition to these, but on a minor scale, every relatively warm and moist surface may serve as a source of atmospheric vapour.

Conversely, relatively warm air cooled from below loses some of its vapour to the surface by condensation. Dew is an example of this: after sunset, the land cools quickly, and the warm night air deposits moisture on it. But the number of water molecules which evaporate from the surface of our planet is very much larger than the number of those which condense upon it. The difference is made up by a host of enterprising molecules which are of particular interest to us, and which we shall follow upon their adventurous journey.

The Formation of Cloud Drops

Much vapour is carried upwards by vertical air currents. These currents arise from the local heating of air, or by its flow across a mountain range, or by the convergence of horizontal air streams. Unfortunately we know as yet very little about the details of vertical currents, such as their extent or their speed. When air rises it expands. The molecules spread over a larger space and their kinetic energy decreases. In other words, rising air cools. Sooner or later it gets cold enough for its water vapour to become slightly super-saturated. If at this stage there was a water surface with the same temperature available, the moist air would lose more molecules towards it than it could gain. The excess moisture content would then decrease by condensation. As there are no permanent water surfaces in the free atmosphere, the vapour molecules tend to build them from scratch. They find that by no means easy.

The attractive force between two single molecules is much smaller than the force with which a whole group holds one of their number. This can be seen immediately in Figure 4.

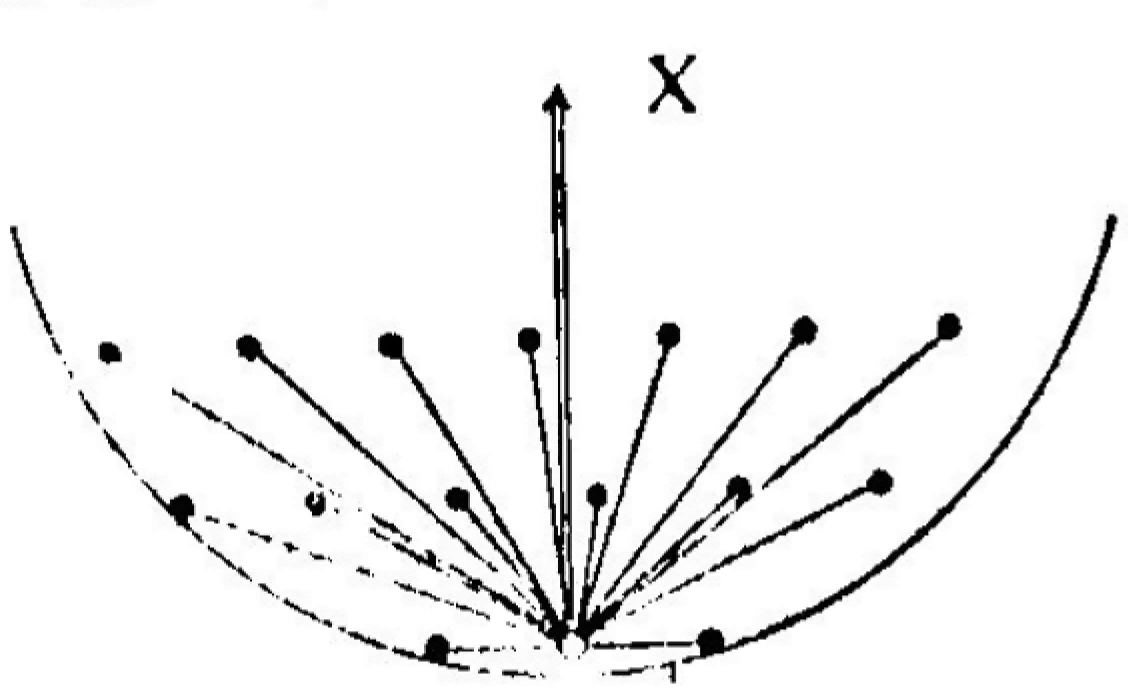


Figure 4a

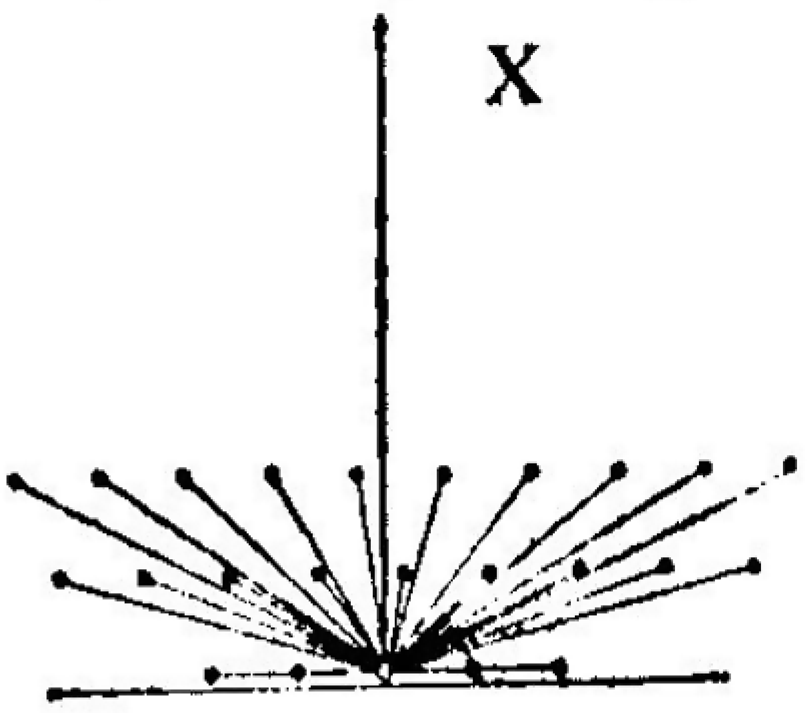


Figure 4b

The attraction between the individual molecules is represented there schematically by the thin lines, and the resultant force by the arrow X. This resultant force is always vertical to the surface. Its effect is similar to that of the elastic stress in a tennis ball. It compels any group of molecules in the liquid phase to assume a spherical shape. This roundness is characteristic for all small drops. A comparison of Figures 4a and 4b now shows immediately that a molecule in the plane or slightly curved surface of a large group is held by more bonds, and hence by a larger resulting force than one in the strongly curved surface of a small droplet. In the latter case the valley of potential energy must be shallow and the molecule has a better chance of escaping on to the plateau of the vapour phase. The small droplet therefore tends readily to disintegrate by evaporation, whilst the large one has a more stable character.

In particular, two molecules will stick together on an average for only about the hundred-millionth part of a second. If a cluster of three is to form, a third vapour molecule has to meet the pair within this interval. The trio can then expect to retain their association some hundred times as long as the first pair. When it is joined by a fourth one, before it breaks up, the quartet will live even longer . . . and so on.

The average natural cloud droplet contains about 500 billion molecules. This is a very large figure. There are about two milliard men on earth, each of whom has probably less than five thousand hairs on his head. The number of all the hairs on all human heads is smaller than the number of molecules in the average cloud droplet. Such a large group can only gather from modest beginnings if there are a great number of molecular collisions within a sufficiently short interval. In order to create these conditions we need a highly super-saturated vapour, *i.e.*, a vapour which contains many more molecules than are necessary to maintain equilibrium with the droplet once it has formed.

Perhaps this can be made clearer by an extension of the simile used for the interpretation of Figure 3. In the first instance we have now no potential energy valley corresponding to the liquid phase, but only the high level plateau of the vapour state. Let us imagine that the plateau is covered by a stretched elastic cloth which hides innumerable small hollows beneath. Picture the molecules as smooth like marbles, rolling at random upon the cloth. Singly each marble is so light that it rolls easily over the covered cavities. Yet if a sufficient number happens to meet simultaneously above one of the hollows, their combined weight may be sufficient to dip the cloth. When that happens, the molecules become trapped together in the depression, and they cannot as easily roll apart.

The chances of such an event taking place increase with the number of marbles on the cloth, and the time interval which they spend together on collision before bouncing apart. In a vapour these factors can be related to the pressure and the temperature. From these the chance occurrence of molecular gatherings is calculable. It appears that on an average only one drop will form in a cubic centimetre every thousand years, when the vapour pressure is three times the saturation pressure. At fourfold saturation pressure one drop could appear every second. Finally, when the vapour pressure is five times the saturation pressure a thousand million drops might form. This is borne out qualitatively by laboratory experiments with so-called cloud chambers.

Atmospheric vapour pressures are at the very most only a fraction—perhaps a few per cent—above saturation value, so our simple picture of drop formation cannot be correct. We must imagine then that the cloth is already depressed into the hollows by small weights, which have been placed there beforehand. The marbles will then quite easily gather in these existing depressions. In the real case our weights are actually small fragments of substances which have the property of attracting water molecules. Most substances have this property to a greater or lesser degree. It can be observed in glass for example, when moisture droplets form on the cold window of a warm room. Ordinary cooking salt attracts water molecules so strongly from the atmosphere that its grains begin to clog the salt cellar on any moist afternoon.

Although the atmospheric condensation 'nuclei' must each contain millions of molecules, they are yet too small to be seen in the microscope. The majority of them are probably made up of (*a*) salt particles which are the residue of evaporating sea spray, (*b*) small blobs of nitric acid which is formed by lightning discharges, or perhaps in the wake of cosmic rays, and (*c*) of particles which come from the smoke of natural fires or from man-made combustion. Dust which is abundant in the air exerts no particularly strong attraction upon water molecules. The number of condensation nuclei is always sufficient for the formation of cloud droplets whenever the vapour pressure rises a fraction—a few per cent at most—above saturation value.

Why Clouds do not Always Rain

There is a great difference between the cloud droplets which first form around the atmospheric condensation nuclei and the drops which make up rain. The cloud droplets are so small, and they sink so slowly, that they evaporate after a fall of only a few inches below the saturation region. That is the reason why many clouds have such an even, well-defined base. Rain drops on the other hand are some million times as heavy. They fall fast, evaporate slowly, and they can reach the ground even through a relatively dry intervening layer of air. There is never enough water vapour in any cloud for all cloud droplets to grow to rain drop size. Only a few can do so. Obviously there must be an agency which allows some droplets to grow whilst others remain small. What is the mechanism of this selective process?

One possible factor is the unequal size of the droplets.

Above we have seen that the small ones evaporate more easily. Their disappearance will increase the host of vapour molecules which can be gobbled up by the bigger drops. As in some parts of the animal kingdom, we find a tendency for the biggest and strongest to grow still further at the expense of their smaller brothers.

But this curvature effect ceases to be effective for droplets above a certain size. The surface force and hence the rate of evaporation is practically the same as it is in a flat water surface for all droplets with a diameter larger than about the ten thousandth part of an inch. The average cloud droplet's diameter is roughly five times as large. This fact suggests that many cloud populations are actually the final product of the selective evolution, which may have started from unequal sizes in the beginning.

In some clouds the droplets do actually grow beyond that stage, yet the further growth is exceedingly slow. It requires a prolonged sojourn of the droplets in a slightly super-saturated surrounding. Conditions of that kind may prevail in slowly rising air currents, and in warm clouds which are cooled by radiational loss of heat. Even then, these clouds seldom produce more than a fine drizzle, whose small drops may reach the earth provided the journey is not too dry.

The big drops which fall from rapidly changing storm clouds with a high base cannot have grown this way. Their occurrence is now often explained by a theory which postulates that they have been born as tiny ice crystals in the upper part of the raining cloud.

Ice Crystals and some of their Properties

The qualities of crystals can be largely explained by the structure of their molecules. A planet's force of gravity depends only upon the distance from its centre. On the other hand the attraction which molecules exert upon others of their kind varies not only with the distance but changes also with the direction. Some directions are greatly preferred. If conditions were similar on our earth, an apple might be a hundred times as heavy in China, say, as it would be in England. In a crystal, the molecules arrange themselves now in such a way that each one meets its neighbour in the direction of its maximum attraction.

The water molecules in particular consist of one oxygen atom and two hydrogen atoms. If we think of the oxygen atom as being in the centre of a three-sided pyramid or tetrahedron, the two small hydrogen atoms will sit on two of the corners, each of which carries a small positive electric charge. The two remaining corners have an equal negative charge. They serve as points of attachment for the positive corners of the neighbouring molecules. The resulting arrangement is shown schematically in plate 19 which represents the oxygen atoms as black balls, and the hydrogen atoms as white. It can be seen that the tetrahedral character of the water molecule leads to a hexagonal arrangement—the crystallisation form of ice.

In ice the molecules are so orientated as to be held by the strongest possible bonds. They cannot escape easily as those from liquid water. This small rate of molecular escape from ice can be made good by recaptures from a vapour which itself contains relatively few molecules. The crystal therefore persists in equilibrium with a vapour of lower pressure than does an open water surface. The difference of saturation pressure between crystals and drops is much larger than that between drops of unequal size.

The potential energy of ice molecules, with their strong mutual ties, is necessarily lower than that of the molecules in liquid water. When a water molecule freezes to a crystal it falls, symbolically speaking, into a very low pit of the potential energy. In doing so it gains kinetic energy which appears as heat passed on to the surroundings, just as in the case of the stone which hits the ground after a fall. This heat is called the heat of crystallisation.

The opposite happens on melting. With rising temperatures the thermal oscillations of the molecules become more vigorous. This increases their chance of jerking out of that potential energy pit, which characterises the ice phase. When that occurs to a sufficiently large number, the regular crystalline arrangement is disrupted and the crystal melts. The heat which is necessary to bring this process about—the so-called heat of fusion—must be equal to the heat which was given up during the freezing process.

The collapse of the very open structure of the ice crystals causes a reduction of volume. In ice, the molecular arrangement needs much space; it is therefore light and floats upon the more densely packed water.

The Importance of Crystallisation Nuclei

The building up of a crystal, solely by the chance collision of vapour molecules, is even less probable than the formation of drops in that way. Although the attractive forces have always the tendency to bind the colliding molecules so as to form a regular lattice, they are opposed by the kinetic energy of the thermal motion. Only below perhaps —70°C. is the thermal energy weak enough to make the formation of pure ice crystals directly from a vapour at all probable. At higher temperatures drops rather than crystals will form in the first instance, when the super-saturation is sufficiently high.

Conditions are different in the presence of suitable nuclei. At temperatures below freezing point, the vapour molecules will tend to attach themselves to any existing surface or edge which recalls the structure of ice. By their combined forces any later arriving molecule will be orientated in such a way as to take up its rightful place in the crystal lattice.

It seems however that most of the crystals which occur in the atmosphere are not built up from vapour molecules at all. They are formed by the freezing of droplets. This event does not occur at the ordinary freezing temperature of 0°C. Perhaps the reason becomes clear if we consider that the water molecules have to be moved slightly apart before they can click into their place in the crystal lattice. We may thus imagine the molecules of ice and water as lying in adjoining potential valleys. Because of a potential ridge between the two, it is impossible for the molecule of the liquid phase to fall—plonk—into the deeper furrow of the ice phase. It has first to pass over this energy hump. Only at very cold temperatures is this obstacle reduced to a kind of shoulder in a slope which leads fairly directly from the potential level of the water phase down into the pit of the ice phase. Because of this potential ridge pure water may be cooled to very low temperatures indeed. Liquid 'super-cooled' water drops have been observed down to —72°C.

The stirring of a super-cooled liquid may bring some of the molecules into the right configuration. A tiny crystal germ formed in this way will immediately grow very fast, and it will continue doing so until the whole mass is solid. The liberated heat of crystallisation may actually heat the water during the process. Alternatively, the freezing process may be precipitated by the introduction of suitable nuclei. Soil, stones and rock will always offer some surfaces which favour crystallisation. That is the reason why ponds and rivers freeze first along their banks and why these bodies of water can never be cooled much below the ordinary freezing point.

The air, too, contains many crystallisation nuclei which float about as very fine dust particles. Some of these will become embedded in cloud drops. As yet we can only conjecture their nature. They are much too small to be seen. However we do not know that they are not very efficient as a centre for crystallisation, for they only begin to act at temperatures of about —13 to —15° centigrade. Clouds which are warmer than that usually consist of droplets alone.

The crystallisation nuclei are apparently much less frequent than the ordinary condensation nuclei. Yet few and inconspicuous as they are they seem to have an inordinately large effect on our lives, and upon the whole aspect of this planet.

Rainbearing Clouds

Let us now consider a cloud at freezing temperature which contains both crystals and droplets. Both a crystal and a drop of the same surface size will be reached by the same number of vapour molecules. But the rate of escape from the ice is smaller than that from the water-surface. Therefore the crystals grow much faster than the droplets. Within a short time the former will tie up so many vapour molecules that life becomes too dry for the latter. The droplets cannot take it. They evaporate and their former molecules attach themselves to the crystals. The process will continue as long as there are droplets about. Meanwhile the crystals are growing larger and larger. Eventually they form heavy flakes which fall towards the earth. When they come down to freezing melting level, the flakes thaw and each forms one or several big rain drops. During their further fall the raindrops may swallow those of the little cloud droplets which happen to be right in their path. That fortifies them sufficiently to survive even long dry passages down to the ground.

The effect is shown schematically in Figure 5. The small low cloud on the left does not even reach up to freezing level. It contains a population of modest droplets alone, and it will not rain as a rule. Equally little effect may be expected from the high cloud above with its exclusive ice crystal society. Even when a cloud rises above freezing level, as that in the middle, it will preserve its character as a homogeneous group of droplets. Only when the droplets are carried up to such lofty heights that some of them do attain crystal status, does the process of rain formation start. It is the beginning of the lost molecule's return journey back to the sea.

Not all rain forms in this way. Particularly in the tropics, precipitation has been quite often observed from

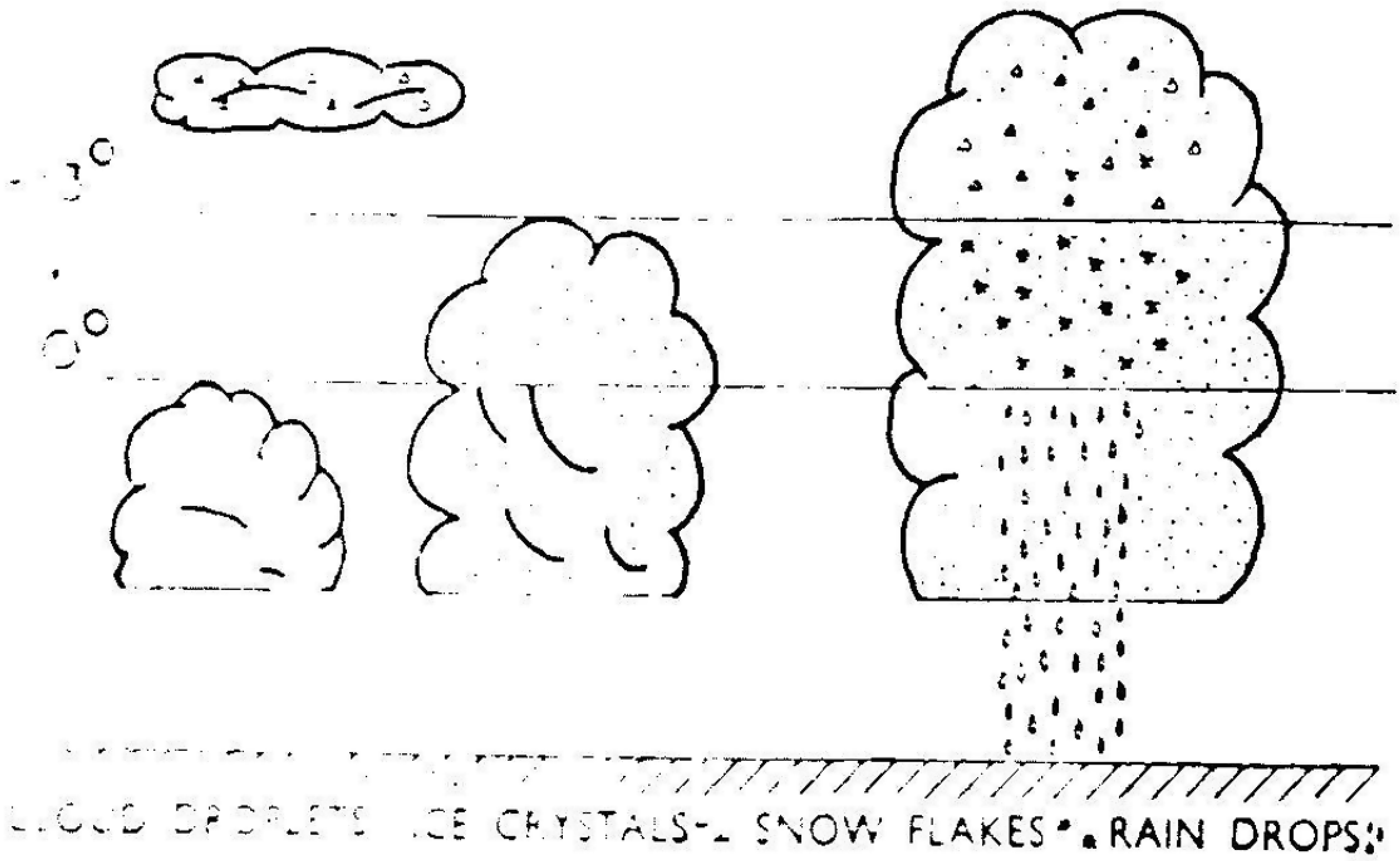


Figure 5

clouds, which did not reach up to freezing level. It appears that these tropical rain clouds are at least ten thousand feet deep. Whilst falling through such a massive cloud, the drops have much time to grow by condensation and by occasional collisions with each other. Yet even on the equator, all really violent downpours seem to come from clouds which reach well up into the crystal region. We may conclude, that although not necessary in every case, the existence of both crystals and droplets within one cloud will always greatly facilitate rainfall.

Man as Rainmaker

The argument so far represents the current ideas on the physics of rain. The development of these ideas during the last fifteen years suggested some possible alterations in the traditional rain-making methods of the witch doctor and the medicine man. Might it not be possible to sow tiny crystal germs into those clouds which rise above freezing level, but which do not quite reach the natural level of crystallisation? Such germs should grow like seeds in fertile soil. When they have grown big enough, they might bring the water down to the earth.

It has now been discovered that very large numbers of small crystal germs are formed when molecules collide in a very cold and highly super-saturated vapour. High degrees of super-saturation can be achieved simply by the rapid cooling of moist air. One way of doing that is to bring the air suddenly into contact with some very cold substance, such as solid carbon dioxide—or dry ice, as it is often called. The temperature of solid carbon dioxide is —80° centigrade. It is so cold that it will hurt your skin seriously if you keep it in your hand. When a lump of carbon dioxide is put on a table in a room, it seems to give off something resembling the bluish smoke of a cigarette. This smoke consists of tiny water ice crystals which form in the air as it eddies past the lump. If we drop a small pellet of the substance through the atmosphere, billions of tiny ice crystal germs form in its trail. If all these small crystals would spread throughout a cloud of super-cooled droplets, each one of them might grow to become a big snowflake, and hence a raindrop. If this were the case, one grain of solid carbon dioxide would be sufficient to release an inch of rain over several square miles. In reality, the tiny germs do not migrate sufficiently. They remain in a relatively limited region, where the competition between them for the available water vapour is so large that only a fraction has a chance to grow. How many will actually do so depends on the type of cloud into which the carbon dioxide has been sown. In particular it depends on the amount of water, on the temperature, turbulence and other physical properties. At present we know very little about these factors inside clouds. Empirical tests have shown however that a hundred to three hundred pounds of granulated dry ice are ample to stimulate an appreciable fall of rain from suitably selected clouds.

Instead of forming crystal germs spontaneously by rapid cooling we could sow particles of other substances into super-cooled clouds. Provided the structure of these particles is suitable, they will serve as nuclei for crystallisation at a level which is lower than that above which the natural nuclei begin to act. Clouds which are not supercooled could be affected by being sprayed with a hygroscopic substance. These substances bind water molecules strongly, and this property causes big drops to form around them. Recent reports indicated indeed, that rain has been precipitated in Russia, by the dusting of clouds with Calcium Chloride, which is a very hygroscopic chemical.

Once crystals are made to grow by any sort of method the heat of crystallisation will be released. The corresponding gain of heat in the whole cloud mass is much greater than the amount of cooling in that part, through which the carbon dioxide had been dropped. The infected cloud thus becomes slightly warmer than the surrounding air. Warm air rises, and that often causes the remarkably fast growth of thunderclouds into the sky. Something similar happened on some of the tests, when artificial crystal germs were planted in clouds over New South Wales. The clouds shot up in a most spectacular way, and when they towered high above all the other clouds, rain came

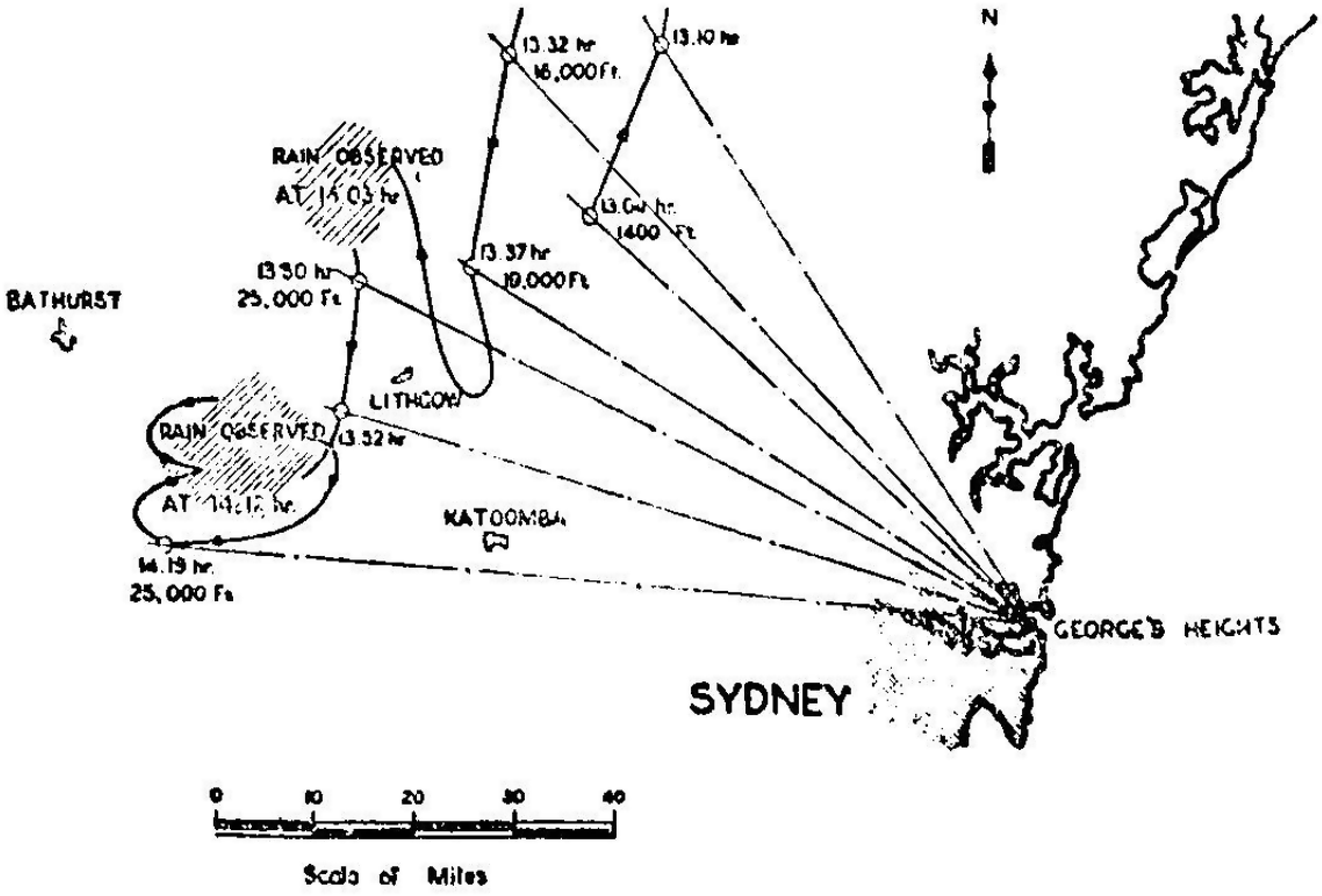


Figure 6—Radar plot of the aircraft track and the two areas where rain echoes were observed to form

out of their base. Plates 20 to 25 illustrate one of these events (see also the map, Figure 6).

To those who carried out the test, this was a thrilling sight. Unfortunately we are not sure as yet how easily it can be repeated. When these first experiments were planned, it was obviously desirable to pick out the most favourable conditions. For all we know at present such conditions may rarely occur.

Before rain-making ceases to be a gamble, it is necessary to learn something of the physical properties of various cloud types, and to observe how often they occur in a given region. This is a fundamental investigation which will occupy scientists for many years. It involves great theoretic and instrumental difficulties, such as computing the relations between vertical air currents and the temperature, air pressure and moisture; or measuring the sizes and numbers of cloud droplets from fast-flying aircraft.

If successful, this investigation ought to teach us something more about the physics of clouds. That is a satisfactory and legitimate aim in itself. With luck, we may get the additional benefit of learning how to cause a slight increase of rain in certain areas. Perhaps we shall find a way of choosing the place on to which it falls. Any discovery of that kind would be of great importance to the people who live in the semi-arid parts of Australia, India and other similar regions. Without further fundamental investigations we cannot say what will or will not be feasible.

One thing is certain. At present we cannot make rain. We can only trigger it off from suitable clouds. This fact alone should preserve us from rain falling according to a departmental schedule as trains follow the railway time table. For the time being at least, we will be still caught out—with or without umbrella—and we need not fear the fading of an old experience which is varied, often stimulating and never quite predictable

Roads are being made Waterproof

C. S. JONES

MANY types of synthetic resins—particularly the melamine groups—are coming to the fore both in the manufacture of plastics, and the processing of textile fabrics for crease-resistance and anti-shrinkage. They also have another use—to make roads "waterproof". They are, of course, largely used in those sections of the textile processing trades where proofing against moisture penetration in fabrics is desirable, but their application to other substances, such as soils, is a striking innovation. It comes from experiments which were undertaken in the U.S. during the war period. It was noticed that miles and miles of roads, on which heavy trucks would travel during the winter months, turned to seas of mud after torrential rain, and remained in that condition until the sun's rays turned them into dust-covered highways. Most of the roads were too far off the beaten track to allow them to be paved or treated with creosoted layers, yet something had to be done. It was Dr. Winterkorn, a soil expert, who emigrated from Heidelberg to U.S.A. in 1931, who accepted the challenge. He got on to the right track, strange to say, through an unrelated problem that arose in Florida. Citrus trees in certain districts were dying; apparently the particular soil in which they had been planted would not absorb water. Dr. Winterkorn deduced that the soil must contain some kind of a "waterproofing" agent. He followed up the clue, tested scores of materials, and found that a number of resinous powders would waterproof surface soil when mixed with it in a ratio as low as 1 to 200. He set to work on his thesis. In collaboration with a chemical manufacturing firm he developed a resin from pine stumps. A mixture of this resin and Portland cement was evolved. Applied in disc form and rolled into the ground to a depth of a few inches, it was found that the surface was impervious to rain, or snow penetration. Thousands of miles of "dirt" roads have since been treated, and reports prove that they have remained dry through seasons of torrential rains and are likely to do so for some years hence.

But, it is pointed out by the inventor, it would be a mistake to assume that anyone can sprinkle any road with this "magic powder" and end the mud nuisance for all time. On the contrary, to effect satisfactory and permanent results soils must be analysed, and experts must apply the correct type of resin stabilizer. This is all the more necessary when it is borne in mind that acid and alkaline soils react differently. No known resin will waterproof sand, nor will it stand up under heavy traffic.

How Messages are Transmitted along Nerves

DR. W. A. H. RUSHTON

Introduction

As soon as animals evolved even to the stage of quite small collections of cells, it became necessary for them to arrange for the transport of chemicals between the central region and the outside. It also was advantageous to have some degree of communication between different parts, and from the first use was made of the transport system to distribute potent chemical messengers (hormones). These hormones are synthesised by certain cells, and may be liberated into the circulation as a result of specific stimuli and so carried to remote parts of the body. The particular feature of the hormone is that it will act upon certain cells and not upon others, so that a special kind of response may be elicited. This has proved a very successful biological device, and physiologists continue to find more and more ways in which our own bodies depend for healthy working upon the scores of hormones circulating in our blood.

But as a means of communication, the hormone system has two important limitations. It is slow, and it is poorly localised. In ourselves, where the chemicals are poured into the veins and carried round in the blood stream, it is obvious that the message cannot be sent faster than the blood travels. It takes about 20 seconds for the blood to complete the circuit of body and lungs, and so we cannot expect to obtain by hormone a response to any stimulus within 10 seconds. Again, since the blood is distributed to every part of the body, the hormone, after thorough mixing in the lungs, must broadcast its message indifferently no matter what may be the site of stimulus. This slow reaction and poor localisation, however, is no drawback where the processes of growth, digestion and general chemical equilibrium are concerned, and it is in this domain that hormones are particularly effective.

But when we turn from considerations of vegetative existence to the relation with the environment, a quicker and preciser system becomes essential. A prime requirement is for the organism to react appropriately to danger or food, and, on the whole, survival rewards him who appreciates the situation most accurately and does the right thing quickest, whether flight or pursuit.

The nervous system is the biological response to these needs. Nerve fibres are like telegraph wires in that they transmit messages fast and far with no transport of material and little expenditure of energy. Information from the outside is received by specialised cells, the sense organs, and these transmit nervous impulses which very quickly reach muscles or glands and stimulate them. It is rare to find a direct connection between a sense cell and a muscle —a private line, as it were. A private line system between *each* sense cell and every muscle that it might require to excite would be very unsatisfactory from two aspects. It would require an enormous number of nerve fibres, and worse still, there would be no co-ordination of the often quite conflicting "orders" sent out from the various sense organs. Thus from the very beginning of nerve evolution there has been a tendency to *centralise* the nerve connections so that a central exchange receives the messages from the sense organs and relays them (to muscles and glands) more or less modified in accordance with the totality of the information received.

It seems obvious that an animal will not be able to react very well to external conditions unless it has good information about those conditions, and this information is entirely supplied by the sense organs—cells specialised to respond primarily to mechanical or chemical changes in their surroundings. The ear and the eye are wonderfully elaborate examples of such specialisation where mechanical resonance and photochemistry are enlisted to enable the cells to appreciate waves emanating from distant objects, and hence to give us some information about the remoter world.

There is perhaps one exception to the statement that all outside information comes to us through the sense organs, namely the case of telepathy. We have a considerable body of rather scattered evidence that perception may be directly transmitted from one mind to another without any sensory intervention. But because it is hard to obtain the conditions for successful telepathic transmission, and because the implications of telepathy are considerable, we must, at present, be careful as to what we build upon this foundation.

It does not seem as though telepathy should affect very greatly the idea that our information about the outside world is entirely supplied through sense organs. These organs would indeed not necessarily be our own, but a very great body of our information in any case is at second hand—read and heard by our own eyes and ears but lived in our imagination through the senses of the narrator. What telepathy brings new is that among the assortment of impressions which pop into consciousness from our own unconscious mental processes, there are occasional impressions which come from someone else's mental processes, and may carry the authority of his sensory perception.

Even accepting telepathy, therefore, our concept of the outside world is derived from the impulse patterns in sensory nerves—indeed this is probably implicit in what we mean by "outside world".

The part played by nerves in the body is so reminiscent of a telegraph system that it is easy to overlook the fact that the message is transmitted by an entirely different application of electricity in the two cases. To illustrate this difference let us consider two familiar ways in which heat may be transmitted.

If a metal rod has one end warmed in a flame, heat will pass along the rod and the temperature will rise even at quite a distance from the flame, especially if the rod is lagged with a thermal insulator. Contrast this system with a lighted cigarette. Here too applied heat may result in the propagation of a temperature rise to a more or less distant region, but the mechanism of propagation is obviously very different. The metal rod is throughout quite passive. Heat is applied, and leaks away where it can. The metal conducts well, the air or other surroundings conduct badly, so that most of the heat passes down the metal, and thus will penetrate some distance with gradual loss of intensity. Any increase in the temperature of the source results in a proportional increase in temperature everywhere in the rod.

The cigarette, on the other hand, is in active combustion. It is not the heat of the match which is conserved and transmitted down in the advancing glow. The match is the trigger which releases the chemical potential of the tobacco, etc., in the cigarette, and the glow is the manifestation of the energy liberated by combustion at the moment. The intensity of the glow will thus not depend upon the temperature of the match (provided that this is adequate to light the cigarette) nor will the brightness decline with the distance of propagation.

Now telegraphic propagation is like the metal rod, and nerve propagation like the cigarette. For the telegraph wire transmits the electric wave owing to good conductivity along the wire and good insulation in other directions, and the size of the wave is proportional to the intensity of the applied electric charge, and gets weaker with distance. But in nerves the activity spreads from point to point by the release of local electric potential. So the impulse does not diminish with distance, nor does its size or nature depend upon the strength of stimulus which excites it to activity (the All-or-None relation).

This is an astonishing limitation. It seems so obvious that a strong external stimulus such as a bright light or a severe pinch must set up a larger impulse in the nerve fibres than a slight stimulus. But though, of course, the nerve message is not the same for strong and weak stimuli, the difference does not lie in the size of impulse conducted, for this depends, not upon the external stimulus, but upon the local conditions of the nerve. Since the only knowledge that we have of the world outside ourselves comes through our sense organs and their nerves, it follows that the shifting pattern of sensory impulses comprises the totality of what we know of the Universe, of Mankind and of everything outside us. All else is the fabrication of our mind. Our familiar picture of the outside world must therefore be largely superfluous, but that it tallies well enough with external reality in certain particulars is shown by the steady advance of verifiable knowledge, *e.g.*, the prediction of eclipses.

We cannot pursue the fascinating question why our concept of the outside world appears so very different from any conceivable integration of the patterns of nerve impulses. It must lie in the properties of the mind which is not solely, nor even chiefly, concerned with exact appreciation of facts. But in the study of the nerve impulse we view at least the bricks from which the mind must build its edifice of factual knowledge.

The Kind of Nerve Studied

While a nerve is in the living body it is rather inaccessible and thus most accurate measurements are only practicable after it has been dissected from the dead animal and set up in special apparatus. It might well be thought that nerves in this state were so moribund, that the information obtained from them was inapplicable to living conditions. Fortunately this is not so.

If an animal is killed quickly by almost any method (*e.g.*, decapitation), though the animal is dead, the nerves of the body are alive. They remain capable servants, though lacking a master. Even after being dissected out they continue to respond to electric shocks in just the same way as they did in the living animal, and they may survive in this state for many hours or even days. So most of the observations made upon carefully dissected nerves apply pretty well to nerves undisturbed in the body.

Now it might be thought that the nerves of man would show particular properties not exhibited in animals whose nervous systems are less specialised. It appears, however, that specialisation has been concentrated upon the nerve centres, which become more and more elaborated as we ascend the evolutionary scale. The simple transmission line—the nerve *fibre*—remains essentially the same from its earliest appearance in the sea anemone, through worms and crabs and squids, to frogs, dogs and man. The study of human nerve conduction therefore need not wait upon the rare opportunity to dissect out a living human nerve, for almost any creature will serve. Frogs have been most commonly used, but we will first consider the giant nerve fibre from the squid, which on account of size may be studied more directly.

The Resting State

The giant nerve fibre of the squid is nearly a millimetre in diameter, which is some hundred times as thick as the nerves in our body. This nerve is a cylindrical tube whose wall is exceedingly thin and fragile, and whose contents are so fluid that they flow out of the cut end unless it is tied.

To understand the cigarette analogy we must learn what is the nature of the stored potential energy, and in what manner it is released so as to propagate an impulse.

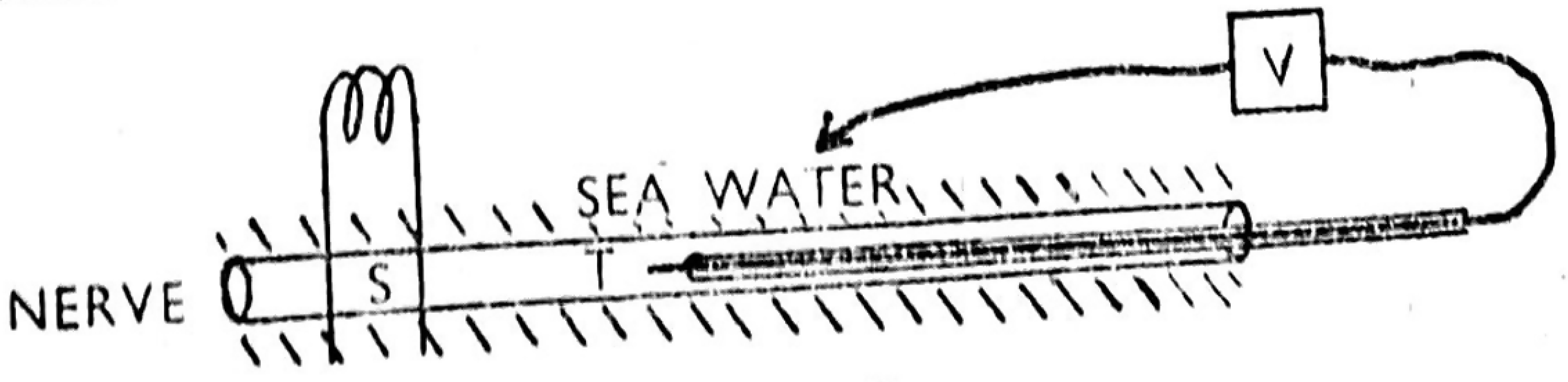


Figure 7

The electrical condition of the fibre's interior has been found by inserting a fine electrical probe. Fig. 7 shows the nerve bathed in sea water to keep it from drying up. Down the centre is a fine wire sealed in a glass capillary tube to insulate it except for the tip, T. The greatest care is needed in inserting the tube, since the nerve is fatally damaged if its wall is touched. But with sufficient skill, the tube may be introduced and left in position down the middle of the fibre with so little disorganisation that the nerve survives and conducts impulses quite normally.

Now if the wire is connected as shown through a voltmeter V to the sea water bathing the nerve, the instrument will record the potential across the nerve membrane. The voltmeter must not draw current, and actually a valve-amplifier was used in conjunction with a cathode ray tube, so that sudden changes in membrane potential due to the passage of the nerve impulse could be instantly recorded.

Now in the resting state there is found to be a potential difference of about 1/20 volt across the nerve membrane, the inside being negative. This is analogous to the chemical potential of the interior of the cigarette and may clearly be the source of the energy required for the propagation of the impulse.

Those who associate electricity chiefly with metals may be surprised to learn that the nerve is able to make its battery without metal pieces and with no other ingredients than are to be found in sea water. Such batteries are of no use in electrical industry, because they give hardly any current, but they arise in general whenever two different salt solutions are brought in contact.

In the case of nerve, the battery of 1/20 volt is directly related to the chemical composition of the fluid inside the nerve. This fluid can be squeezed out and analysed, and it is found to contain potassium in a concentration 30 times that of sea water. Why does not the potassium leak out into the sea water? The obvious suggestion is that the nerve membrane is "potassium-tight", but this is not the case. If some potassium is added to the sea water outside the nerve, it will enter the nerve, actually going from the dilute to the concentrated solution, as may be proved by direct analysis. But if potassium *can* pass through the membrane why does it remain concentrated inside? The reason is electrical. Potassium in solution has a positive charge which must always be neutralised by association with another chemical negatively charged, *e.g.* with chloride particles in sea water. Now inside the fibre the negative particles are part of the nerve protoplasm, so when the potassium seeks to escape from the interior it is held by its attraction to the protoplasm. An equilibrium is thus reached where the tendency of the crowded potassium particles to leak away is exactly compensated by the electrical potential difference (negative inside) impelling these positive particles to return. From the known potassium concentrations in sea and in nerve it is possible to calculate the membrane potential difference necessary to restrain them. This agrees with the value found by the experiment of Fig. 7.

We thus conclude that the resting potential difference across the membrane is due to the fact that the inside of the nerve contains concentrated potassium which could escape, were it not for the electric attraction to the fixed protoplasm.

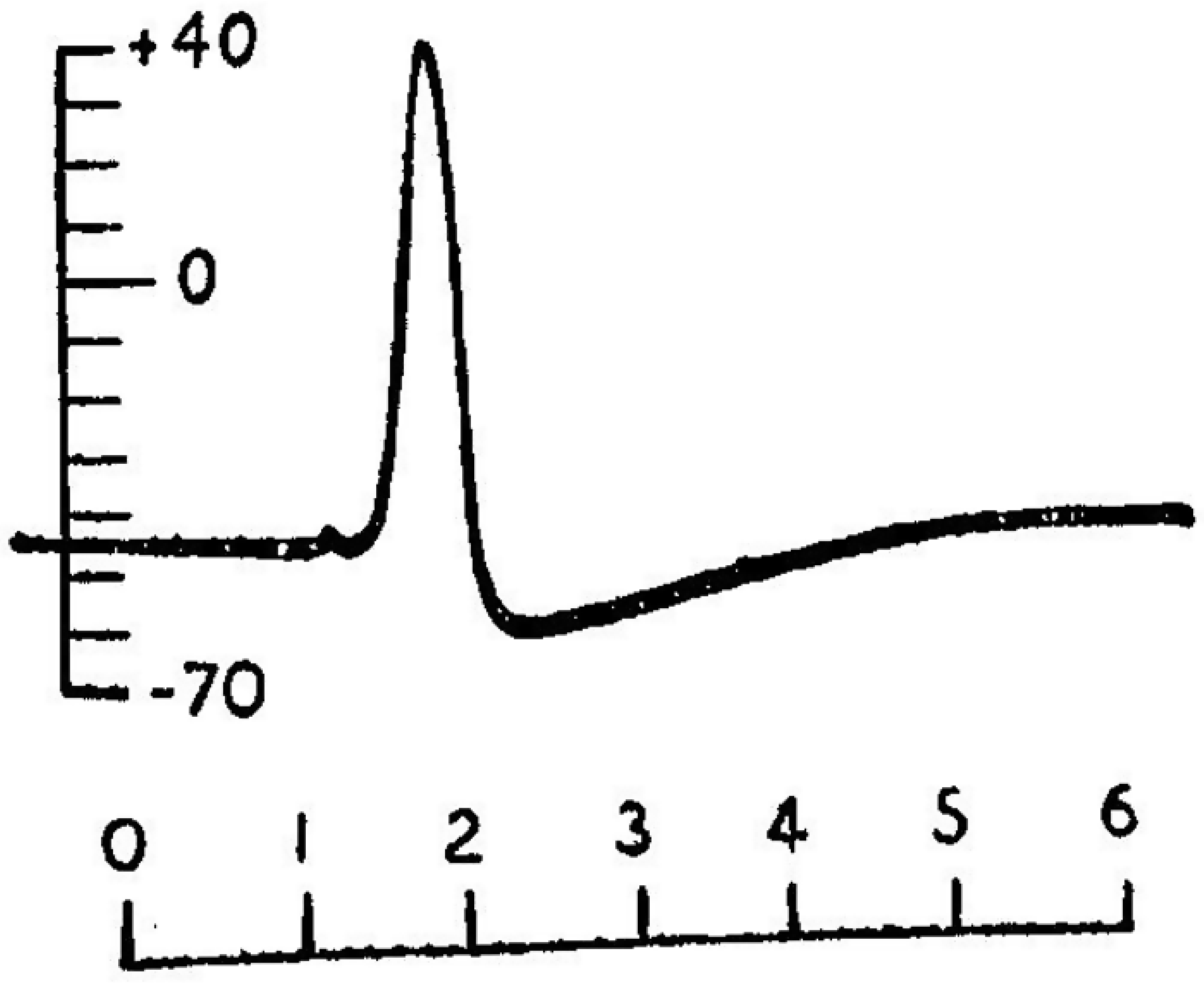


Figure 8

The Active State

Now, turning again to Fig. 7 let us consider what happens when the nerve is excited by applying a shock through the electrodes S, situated some distance away from T. If the shock is weak, nothing will be recorded, and if in succession stronger and stronger shocks are applied, practically nothing will be seen in the voltmeter record until suddenly the response shown in Fig. 8 appears. Shocks stronger than this "threshold" value continue to give just the same record. The response is therefore like the cigarette glow, which is not elicited at all unless the lighter is hot enough, and which is of the same brightness no matter how much hotter than threshold the lighter may be (All-or-None). This record, then, is related to the energy release of the nerve in activity, and repays closer inspection. The time scale is in thousandths of a second (msec.) so the changes are exceedingly rapid. The vertical scale gives the potential of the inside relative to the sea water as zero, and shows that the resting condition (1/20 volt negative) swings over momentarily to about 1/20 volt positive. The wave is preceded by a tiny upward notch. This represents the physical spread of the stimulating shock. It is the only thing recorded when the stimulus is below threshold strength, and it serves to show the exact instant when the shock was applied. The short interval between the application of the shock and the beginning of the nerve response is the time taken for the nerve impulse to be conducted from S to T. Records obtained when S is moved further and further from T show corresponding increases in the interval between the notch and the wave in the records, and from such comparison the impulse is found to travel at a constant speed of about 20 metres per sec. (=45 m.p.h.).

In suggesting that the electric wave is analogous the to glowing reaction of the cigarette we have implied that the wave *is* the energy change responsible for propagation. Suppose we had suggested that the wave was analogous to the smoke given off from the cigarette, this would have equally satisfied all the relations so far considered, but it will take away much of our interest if it turns out that the electric record is only a by-product of the effective process. Put another way, our engineering interest in the fire of a steam engine will be very different if we believe it to be there to drive the engine or only to warm the engine driver. Our interest in the electric wave in nerve will thus depend upon satisfactory answers to these two questions: "How could the wave be the actual mechanism of propagation ?" "What are the grounds for believing that this possibility is in fact true ?"

We know that nerves can be excited to activity by an electrical shock, and indeed we have just considered an example of this. But the electric wave of Fig. 8 is itself an electric shock, which, though weak, is intimately applied to the region of nerve just beyond the place which is active at the moment. Certainly it is conceivable that the "action current" stimulates the next region, thus making *it* active, so that its action current excites the next region, and so on. Does this in fact happen ?

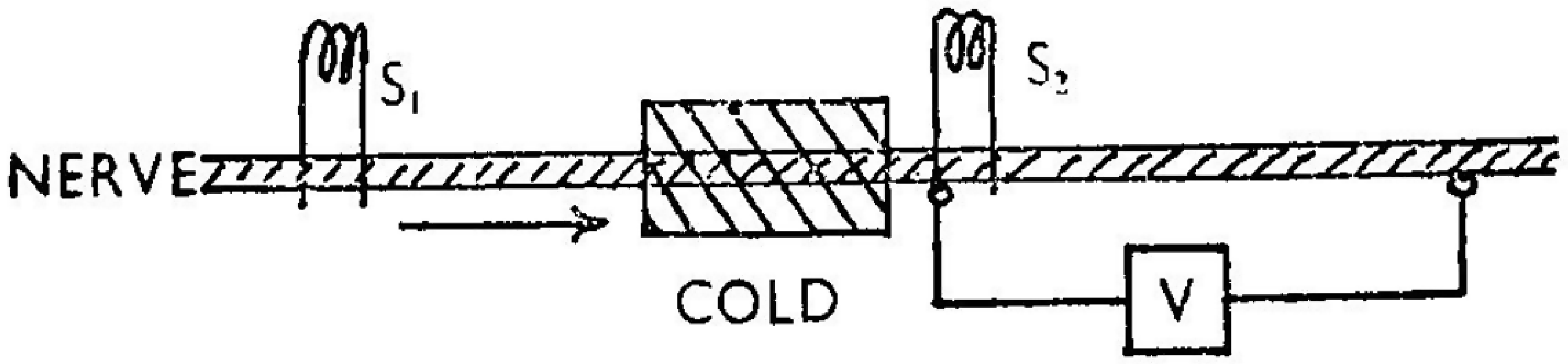


Figure 9

The proof of this is given by the experiment of Fig. 9. If the nerves, say, of our hands become very cold they cease to conduct, and we become numb. A nerve is dissected from a frog and the region is cooled (as shown) until the impulse arising from the shock S_1 is just unable to pass. Now it is known that a current applied to a nerve will spread for several millimetres away from the site of application. Thus despite the fact that the active conduction is extinguished in the cold region, we might expect to find some "action current" spreading passively into the region S_2

This expectation can be quantitatively verified, so there is no doubt that current does spread in advance of the active region. But the point is "Does this current excite?"

If a second shock is applied through the electrodes S_2 the strength required to excite may be much diminished if the shock is timed to coincide with the wave of current spread from the extinguished impulse. In favourable conditions S_2 may still excite if only 10 per cent of its normal threshold, so there can be no doubt that the spread of action current which is 90 per cent effective at S_2 would be fully effective very close to the active region. Hence the record of Fig. 8 shows the essential process of conduction.

Excitation

We have obtained some understanding both of the nature of the resting potential in nerve and of the mechanism of propagation. To complete our causal picture we must know why an applied shock causes the sudden oscillation of potential shown in Fig. 8. This in essence is the question put by Galvani two centuries ago when he first discovered electricity, and we still are unable to answer it. It may, however, be worth indicating briefly the direction in which the answer is being sought.

When a nerve is active it is found that potassium leaks out. Now we have seen that potassium is concentrated within the nerve and only constrained there by the electrical force across the membrane. So that it is not surprising to find that when this force is reversed (Fig. 8) the potassium rushes out for one millisecond under combined action of diffusion and electricity. But we still need to square this situation with the conditions of electrical neutrality within the nerve fibre. It potassium cannot leave in the resting state because it is bound to neutralise the protoplasm, in activity it will also be held unless relieved by the introduction from outside of some other positive particles, for instance, sodium.

As is well known, sea water consists chiefly of a solution of sodium chloride, but the inside of the nerve contains little sodium, so that there is a disparity of sodium across the nerve membrane like that of potassium, but in the opposite direction. Now the sodium cannot be restrained by the electrical forces, since these actually urge positive particles inwards (as we have seen). So we must conclude that the nerve is like a ship which will not allow the sodium of the sea to accumulate within, either because it is "sodium-tight" or because the pumps are kept working (as recent work with radio-active isotopes suggests).

Now suppose that a shock breaches a hole in the ship's side so that sodium pours in—for, though no visible hole is made, the electrical resistance of the nerve membrane suddenly falls nearly to zero. The inrush of positive particles may well cause the positive swing of the potential seen in Fig. 8, and sodium will replace some potassium in the protoplasm and thus account for the observed escape of potassium to the exterior. But how does the shock "breach a hole" in the nerve membrane? We are familiar with the material property of "giving way" before too great a strain. The safety valve will yield, or the boiler will burst, or the string will snap, or the electric insulation will break down, if the applied tension is excessive. Not so is the membrane response.

There is a more subtle set of devices which we know well—knots, buckles, ratchets, catches and friction jams of all kinds. The trick about these things is that if you would loosen them you must first oppose the motion which is your ultimate object. Swell your belly and you may burst your belt, but it will never unbuckle that way. If you would ease yourself, first tighten a little.

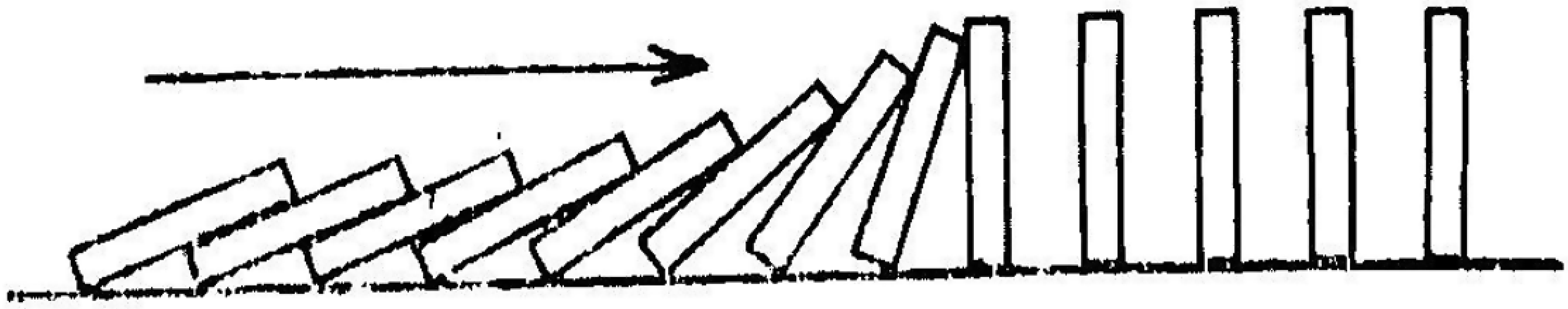


Figure 10

The nerve mechanism lies in this class, for an electric current will only stimulate when it passes through the membrane in the direction opposite to that of the active discharge. The current has first to depolarise the nerve, i.e., to lessen the resting electric strain. This lifts a restraining catch, and now the system rapidly discharges until the fall of the catch again restrains it. A row of bricks standing on end can propagate a wave of collapse (Fig. 10) in this way. Each brick is a "catch mechanism" in that it needs the centre of gravity to be lifted a little before it can fall, and the fall of each releases the catch of the next.

The Living Nerve

We have considered the propagation of a single impulse along a stretch of nerve fibre, but to view this in its perspective as a bodily activity needs some extension both in time and space.

Normally impulses follow each other down a nerve fibre in more or less rapid sequence, which brings us to the question of the recovery process, maintenance and fatigue.

Again, the significance of an impulse train lies in what it does at the other end of the line, and this involves nerve-muscle action at one end and central nervous coordination at the other.

The present account of nerve conduction will therefore conclude by touching upon these questions in order to show the nerve impulse a little more clearly in its biological setting.

Recovery

As soon as the wave of activity is ended at any place in the nerve, this place is ready to conduct a second wave. The fastest nerve fibres of our bodies can conduct up to a thousand impulses per second, though they are rarely called upon to exceed half this frequency.

The fact that a nerve is ready to conduct again as soon as the last wave has passed, shows that the resting potential energy is not all used up (as in the case of the cigarette) and this is confirmed by the return of the wave (Fig. 8) to the former resting potential level instead of to zero.

Either, like the escapement of a clock, the catch falls again before very much of the potential energy has run down, or else, like a water closet tank, there is connection with a much larger reservoir, so that the tank may be emptied by the local action but is then rapidly refilled from the reservoir. This last example constitutes quite a good analogy for what in fact is found. The discharge from the tank is independent of the strength of stimulus (All-or-None relation). Immediately after the discharge there is a short period during which a second discharge cannot be obtained, no matter how strong the stimulus (absolute refractory period). And following this there is an interval during which the stimulus required is greater

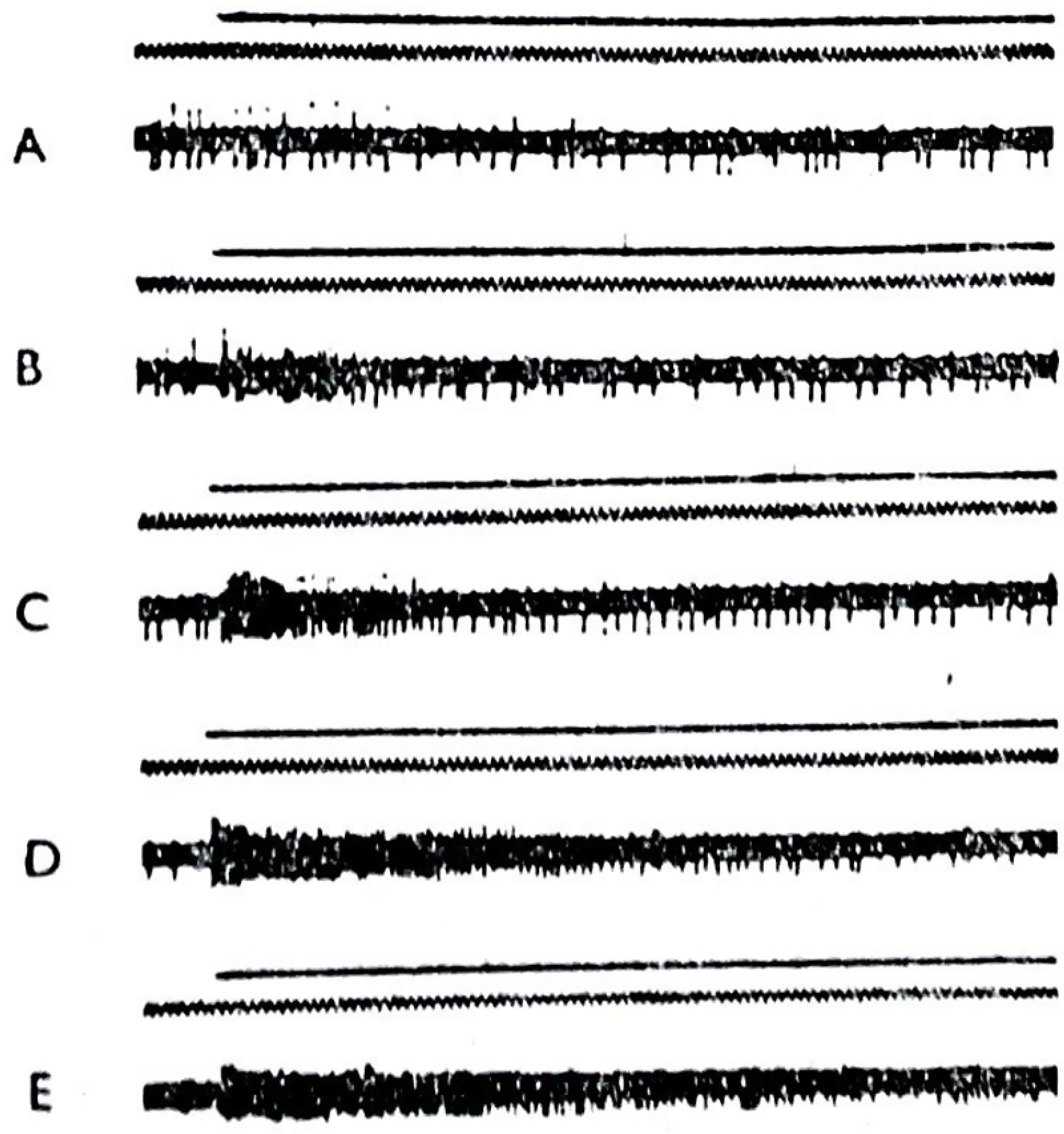


Figure 11—Records of nerve impulses from the eye when a light is switched on. The top line in each group shows the illuminated period, the thick black line with fringe is the nerve-impulse record. A to E, progressively brighter light.

and the discharge resulting is smaller than normal (relative refractory period).

This latter property may be of great importance in helping us to appreciate the world outside us. We have seen that the only way in which a nerve fibre can vary its message is by altering its rhythm. But the information which it seems to convey is about the *strength* of stimulus (*e.g.*, brightness of light, severity of a pinch, etc.) not its rhythmic quality. Since a strong shock is needed to excite a second impulse rapidly after a first, only an intense stimulus will be able to generate the highest frequencies of impulses. Inversely, it is likely that strong stimuli at the body surface are inferred when a fast train of impulses arrives at the brain.

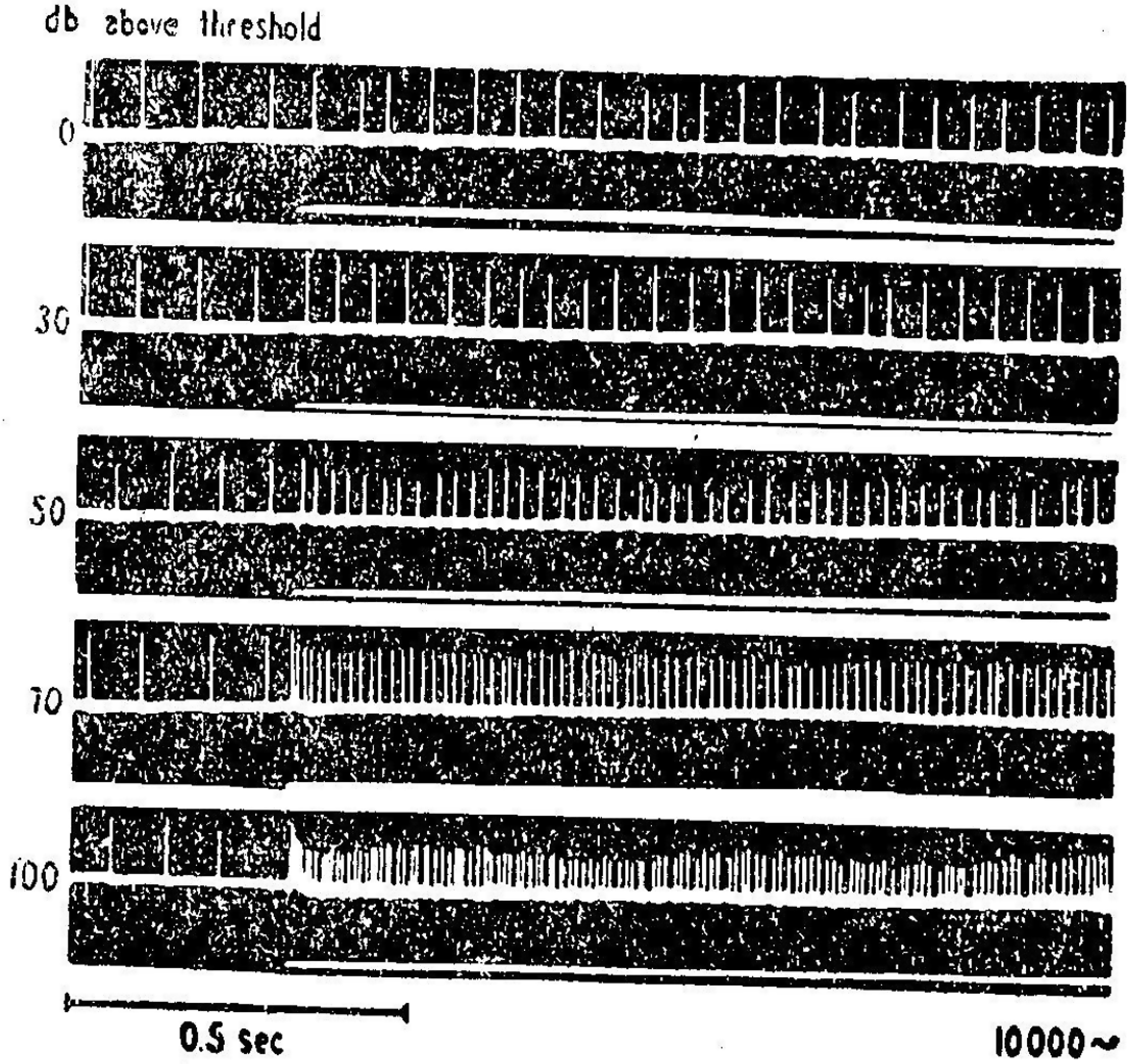


Figure 12—Records of nerve impulses from the ear in response to louder and louder sound. The lower white line in each record shows when the stimulating sound is made.

It would be misleading to suppose that the foregoing was the only or even the main causal chain between the intensity of stimulus and the nerve pattern received by the brain, but it shows one way in which the brain may appreciate stimulus' strength, despite the unvarying size of nerve response. Actual records from a single nerve fibre of the eye and the ear are shown in Figs. 11 and 12. The stronger the light or sound, the more closely the impulses follow each other, but there is no change in their size.

Fatigue and Maintenance

We are familiar with one idea of nerve fatigue—the condition which is cured by sleep, or a holiday, or even a change of work. Whatever this phenomenon may be, it certainly is not a property of conduction in the nerve fibre. For nerves will continue to conduct impulses at the rate of 100 per second for hours on end without showing any sign of fatigue, and in cases of complete "nervous exhaustion" the nerve fibres still appear to be normal. No, nerve fatigue is an affection, not of the fibres but of the nerve centres (brain and spinal cord), which have some properties very different from those we have been considering. But though our nerve fibres are unfatiguable in ordinary circumstances, they need a more or less constant blood supply if they are to maintain their function.

If we stay for some time with one knee crossed over the other, the upper foot may "go to sleep" and become quite numb. Many people suppose that this is because the artery behind the knee has been compressed and so the foot is deprived of its blood supply. You may satisfy yourself that this is not the case, however, on the next occasion that your foot goes to sleep. For, while maintaining the "numbing position" of the legs it is easy to insert a finger behind the knee and feel a clear space there with no contact, far less compression, upon the region where the artery runs. More convincing still, the pulse may be distinctly felt in the foot.

There are two places on the foot where a pulse may normally be felt, though not so strongly as at the wrist. One is in the midline in front at about the level of the ankle bones, and the other is just behind the inner ankle bone. These pulses may be felt to beat quite normally when the foot is "asleep", proving with certainty that leg-crossing does not cut off the blood to the foot.

What is compressed, however, is a nerve which runs over the bone (neck of the fibula) on the outer aspect of the leg just below the knee. This comes nicely in contact with the knee-cap of the lower leg and so the nerve is pressed between the two bones. But, it may be asked, "If the nerve is pressed near the knee why is it *the foot* that becomes numb?"

Perhaps you have given this nerve a knock (as I often have) when carrying a suitcase. You will then have noticed that in addition to the ordinary sense of being knocked, there is a special tingling chiefly in the foot.

Nearly everyone has experienced a similar thing on knocking the "funny bone"; though the inner aspect of the elbow is struck, the special tingling is felt in the region of the little finger.

Now if by anatomical dissection we trace the course of these nerves which lie near the surface at knee and elbow, it is found that the fibres end in the very places where the tingling is felt. So it appears that if we bump or paralyse a nerve trunk, we get tingling or numbness "referred" to the place where the fibres have their distant endings.

This result is a necessary consequence of the idea, stated earlier, that our only information of the outside is conveyed by nerves in unit impulses. For since the impulse which arrives at the central nervous system is the same whether it starts at the nerve ending or is generated by a bump on the "funny bone" half way up the nerve, the centre cannot distinguish between the two and simply says "I am getting impulses in the fibres which normally conduct from the little finger". In the same way when the leg nerve is compressed, the impulses from the foot cannot get past and so the foot feels numb.

Now suppose the legs are at last uncrossed. Within a minute, feeling returns. Pins and needles! This intense sensation is certainly localised in the region which had been numb and it arises as the direct result of lifting the compression. Is it possible then that the sensation does not arise in the foot at all but only in the place on the nerve trunk which had been compressed? This indeed is the truth (though it is hard to believe it while you are feeling the pricks in your foot), for pins and needles may still be obtained apparently from the foot, when the nerves just below the compressed region have been quite put out of action by injecting them with the local anæsthetic novocain. Since now no sensation of any kind can actually be conveyed from foot to brain, the pins and needles must really be arising near the knee, but they are referred to the nerve endings precisely as in the case of the knock on the "funny bone".

When we have pins and needles we try to keep our foot very still, because tapping against the ground, or indeed any movement, makes the condition worse. This must mean that, though pins and needles *can* occur when all impulses from the foot are blocked by novocain, nevertheless the condition is accentuated when impulses do get through. It therefore appears that the region of nerve released from compression is in a very irritable state and capable of generating nerve impulses on its own, and it is clear that this irritability is further increased by impulses arriving from below.

In what way does compression block the nerve impulse? A block *can* occur owing to deformation of nerve structure, but recovery in such a case takes many weeks, not just a minute or two. In crossing the legs the compression does not affect nerve structure at all, but it closes the minute blood vessels that supply the short stretch of nerve compressed. Careful measurements have shown that the foot will only become numb when the nerve is squeezed sufficiently to close the vessels. A compression two or three times as great has no greater paralysing action—for if the vessels are shut the blood supply is stopped, and it does not matter how much tighter shut they are made. Normally, the blood brings oxygen and food to the nerve and removes the waste products so that the arrest of circulation might paralyse through stopping any of these things, but it is probable that oxygen lack is the most important. Parts of the brain are rapidly paralysed by deficient oxygen and one loses consciousness within a minute or so of removing oxygen from the lungs. The nerve trunks, however, may be deprived of oxygen for about a quarter of an hour before becoming paralysed. This is partly because of the great efficiency of nerve fibres whose maintenance and activity is conducted with extremely small oxygen consumption. A frog's nerve conducting 250 impulses a second takes three days to use up its own volume of oxygen. Though active human nerves would use more than this, it is clear that a very small store of oxygen upon which the nerve could draw during asphyxia would account for the survival time of some fifteen minutes.

We may thus largely leave aside the question of maintenance in considering the normal working of nerves seeing that their demands are so small and easily satisfied. But it must be remembered that in the long-term balance-sheet there are nutritional factors, such as vitamin B, which are essential.

Moreover, beneath this still mask of meticulous efficiency lies the living face of an organic unit which once grew out to form its present structure and, if ever injured, will grow again in the attempt to re-establish its severed continuity.

The Action of the Nerve Impulse

The nerve impulse is conducted along the fibre by the electrical mechanism we have considered. Its action is to stimulate another cell, *e.g.*, muscle, gland or another nerve cell. It is natural to suppose that the second cell is also stimulated electrically by the nerve action current. But where this has been most carefully studied it is found not to be the case.

In considering earlier the objections to stimulation by hormones, we noted that the chemical message travelled too slowly and was broadcast too freely, Both these objections would be overcome if the hormone were secreted not by one general gland discharging its products through the blood stream, but by a sprinkling of minute gland elements situated one at the termination of each nerve fibre. For the message would travel swiftly down the nerve, and the hormone would be intimately applied to the structure at its termination. In the case of every nerve which conducts away from the central nervous system it has been found that there is in fact such a hormone secreted. The hormone is not the same for all nerves, but in each particular case it is found that the next cell (muscle, gland or another nerve cell) is sensitive to the external application of this particular hormone. Thus there is strong reason to suppose that the nerve *ending* stimulates by the intimate application of a minute dose of hormone.

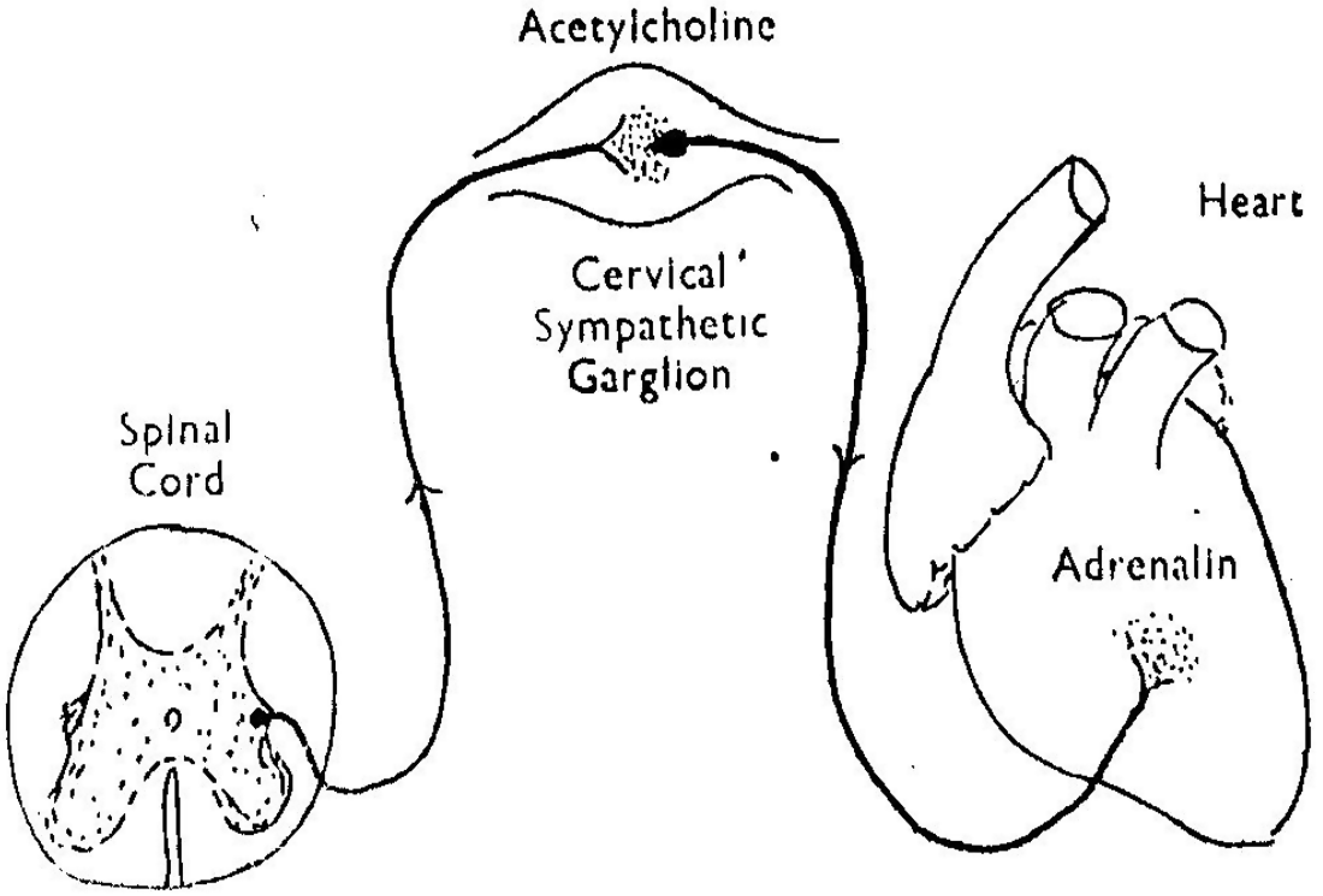


Figure 13

Fig. 13 shows schematically the sympathetic nerve relay which runs from the spinal cord to the heart and makes it beat faster. The first nerve runs out from the spinal cord to a nerve centre (ganglion) in the neck. Here it secretes acetylcholine, which hormone will excite the second nerve leading to the heart. The second nerve ending secretes a different hormone, adrenalin, which acts upon the heart and quickens the beat. The heart is quickened in the same way when adrenalin, synthesised chemically, is injected into a vein and in this manner carried to the heart, or when the adrenal gland (a typical hormone-producing gland) pours adrenalin into the general circulation. In the latter cases, however, the effects are not simply confined to the heart but are widespread, and appear after a greater delay owing to slow blood transport.

We have spoken of the special properties of the endings of outgoing nerves. What of the incoming nerves that ramify in the tangle of the central nervous system; do they operate by electricity or do they also secrete a single hormone or one of many?

As yet we do not know. There are many close analogies between central nervous conduction and the peripheral conduction where hormones are found to act. But we may not conclude that hormones must act centrally too, because there are many central features which have no peripheral counterpart. Moreover Nature has a trick of producing the same end result by totally different kinds of mechanisms, so we must exercise caution in the application of analogy.

The reader must therefore be left to speculate for himself how far his nervous coordination, his reinforcements and his inhibitions are due to the accumulation and antagonism, the drift and the destruction, of chemical agents in his brain.

A Century of British Chemistry

DR. F. SHERWOOD TAYLOR

IN this year 1947 the Chemical Society is celebrating its centenary, which, but for the war, would have been celebrated in 1941. This is therefore an occasion when we may well consider the achievements of our countrymen during the portentous century that lies behind us.

The science of Chemistry is concerned with the distinctive properties of the different kinds of matter. It seeks to connect these properties with the fine structure of matter and through this knowledge to prepare new kinds and to use those already known to the best advantage.

It follows then that the history of theoretical Chemistry is largely concerned with the discovery of the invisible structure of substances, and modern chemistry begins with the Atomic Theory of John Dalton, who adapted a theory which had been current for two thousand years and more to explain the relationships between the quantities of chemical elements in chemical compounds. To him we owe the ideas of atomic weight and of the chemical formula; ideas which originated three capital problems in chemistry; first the relationship between the relative weights of atoms of elements (atomic weights) and the proportions in which those elements combine; secondly the manner in which the atoms of the elements are grouped in molecules, and thirdly the nature of the forces that group them.

Sir Humphry Davy, who founded the theory of electrolysis, supposed that the atoms in a compound were held together by the mutual attraction of positive and negative electrical charges upon them. Berzelius, in Sweden, who developed Dalton's theories to the stage of a practical foundation for chemistry, held a similar view, supposing that every molecule, and every group within the molecule, consisted of two portions held together by electrically opposite attractions. This, the dualistic theory of chemical combination, was true for electrolytes—acids, bases and salts—but could not give an adequate explanation of the formulæ of organic compounds. Fatal to the dualistic theory was the discovery that electronegative chlorine could be substituted for electropositive hydrogen in a compound without marked alteration in its properties, and the dualistic theory, for organic compounds at least, had gradually to give place to various *type-theories*. These theories, put forward by Dumas, Gerhardt, Laurent and others, accepted the existence of *classes* of compounds, and in writing their formulæ grouped the atom-symbols so as to make apparent the chemical reactions these classes had in common; but these formulæ were not generally considered to represent actual molecular structure, but only to set out the atoms in groups expressing the characteristic reactions of the compound.

As late as the eighteen-fifties there was no certainty about atomic weights.* Thus some gave carbon the atomic weight of 12, others of 6; some gave oxygen as 16, others as 8. The formula C_2H_6O with carbon as 12 and oxygen as 16, expresses the same composition as the formula $C_2H_6O_4$ with carbon as 6 and oxygen as 8, but the two formulæ make quite different statements about the structure of these compounds. Thus even in 1850 it was doubtful whether alcohol was a compound of ether and water or ether was a compound of two molecules of alcohol minus water: for both views agreed with the formulæ. In 1852 one of our finest chemists, Alexander Williamson, settled this question by synthesising ether from the iodine compound of alcohol and the sodium compound of alcohol, and so showed it contained two molecules of alcohol. He was thus led to formulate alcohol and ether on the water type.

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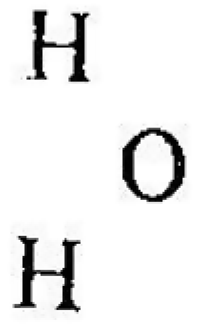
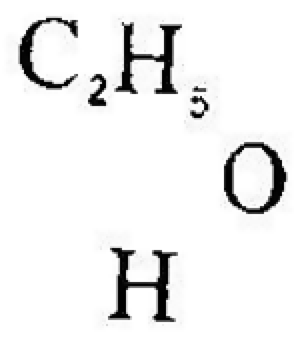
* i.e., *relative* atomic weights, compared with hydrogen=1; not absolute weight in grammes.



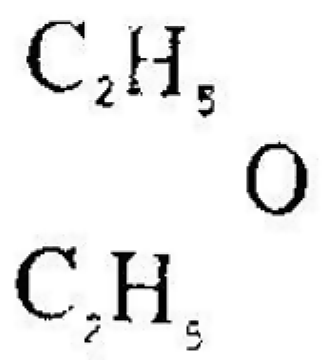
$\begin{matrix}H & \\ & O \\ H & \end{matrix}$

water



$\begin{matrix}C_2H_5 & \\ & O \\ H & \end{matrix}$

alcohol



$\begin{matrix}C_2H_5 & \\ & O \\ C_2H_5 & \end{matrix}$

ether

Here he is, in effect, giving to an atom of oxygen the power to combine with two groups—what was later called a *valency* of two.

In 1852 Edward Frankland took a further step forward and, as a result of his studies of the organic compounds of nitrogen, phosphorus, arsenic and antimony, came to the conclusion that an atom of these elements would combine with *three* or *five* atoms of hydrogen, chlorine, iodine or oxygen ($O=8$). A. S. Couper, in 1858, introduced the idea of the quadrivalency of carbon and the familiar valency bond of today. Couper unhappily fell ill and it was left to Kekulé to develop these ideas. In this year, Cannizzaro wrote his famous pamphlet which established true values for atomic weights, and these, with the idea of valency (combining power) and valency linkages, allowed structural chemistry to begin its course.

The relationships between the valencies, chemical properties and atomic weights of the elements is bound up with the Periodic Law of Mendeléeff. The central idea of this, that there were relationships between the atomic weights of chemically similar elements, came near to discovery in this country, for the tables of the elements put forward by John Newlands and by William Odling contained the essential idea of Mendeléeff, though they lacked the masterly exposition of the evidence and exploration of the consequences that distinguished the work of the Russian savant.

The greatest contribution of British men of science to the problem of the relationships between the valencies, properties and atomic weights of the elements was the brilliant series of researches, employing physical techniques, that led up to the theory of the structure of the atom. We may first remember the hypothesis of William

Prout (1815) that all atomic weights were exact multiples of that of hydrogen, which, although contrary to the facts then known, was found after the discovery of isotopes to have a substratum of truth. Then we turn to William Crookes's investigations of cathode-rays (1879), which seemed to him to contain a 'fourth state of matter'. J. J. Thomson in 1897 proved these rays to consist of streams of negatively charged particles very much lighter than the lightest atom. These particles, later called 'electrons', could be elicited from every kind of matter and formed the first evidence of a factor common to all the elements. At this time X-rays had been discovered by Röntgen and this had led to the researches of Becquerel and the Curies, which established the existence of radioactivity and its association with certain metals. The nature of this phenomenon was first made clear by Ernest Rutherford and Frederick Soddy, who showed that radioactivity was the disintegration of atoms and that the radioactive elements were being transmuted into other elements. Soddy's discovery of isotopes, elements of apparently identical properties but different atomic weights, explained the anomalies that had been noticed in the Periodic Table, and, since that date, F. W. Aston's invention of the mass spectrograph, a development of J. J. Thomson's positive ray-apparatus, has shown that almost all elements are mixtures of isotopes. The disintegration theory of radioactivity led Rutherford in 1911 to put forward the nuclear theory of the atom, giving evidence that it consisted of a positive nucleus, minute but possessing nearly all the mass of the atom, surrounded by a cloud of electrons. The nucleus of the hydrogen atom he called the *proton.* This theory gave a theoretical foundation for the periodic table. The number of the element in the table, starting from hydrogen as 1, was taken to be the nuclear charge, and this was proved by H. G. J. Moseley who, utilising Bragg's method of X-ray spectroscopy, was able to determine the atomic number of an element from the frequency of the X-rays emitted by it when used as target in a cathode-ray tube. On these British researches Niels Bohr founded his brilliant theory of the structure of the various atoms, and the groups of electrons that characterise the elements of each group of the periodic table. This work also led to the understanding of chemical combination, for N. V. Sidgwick, gathering together a number of partial explanations, showed how the Bohr atom accounted for the three different types of valency—the electrovalency of salts, the covalency of organic compounds and the co-ordinate valency of the ammines and other such compounds, and thereby opened up many new lines of research.

This work has thus brought us to a useful, if not complete, knowledge of the relationship between the different types of atom, and of the manner in which they combine. The deduction of the *arrangement* of the atoms in the molecule, indicated by the structural formulæ of chemical compounds, has been perhaps the principal work of chemists during the past century. It is impossible to recount the various methods employed, for each compound presents a different problem: suffice it to say that reasoning based on observed properties and reactions has settled the formulæ of all the simpler compounds known to us, and in recent years this has been supplemented by several physical methods.

But in chemistry we do not deal with single atoms or molecules but with aggregates of them—solids, liquids, gases, solutions and mixtures—and so the study of the physical properties of the various chemical compounds has proved to be necessary to the understanding of their chemical reactions. No part of Physical Chemistry, as this study is termed, has been more important than the investigation of the properties of gases. The first president of the Chemical Society, Thomas Graham,* discovered the laws of diffusion of gases, which gave us a new means of determining their densities and the first physical means of separating two gases. A tremendous amount of funda-

* See Plate 32.

mental physical and mathematical work on the kinetic theory of gases was done by such men as Clerk Maxwell, Joule and Kelvin, though this belongs rather to physics than to chemistry; but a very important contribution, both theoretical and practical, was made by the many British chemists who studied the liquefaction of gases. Davy made a beginning, and Faraday, between 1823 and 1845, liquefied all the known gases that could be condensed by cooling to −110°C. at pressures up to 50 atmospheres. Certain gases resisted his efforts, and Thomas Andrews in 1869 put forward the theory of the *critical state*, and thereby showed the impossibility of liquefying gases above their critical temperatures. Efforts to liquefy such gases as oxygen, nitrogen and hydrogen continued to have small success until 1895-6, when Linde in Germany, and James Dewar and William Hampson in England, made use of the Joule-Thompson principle (1853) that a gas is considerably cooled when it is allowed to expand from a state of high compression. This, combined with regenerative cooling, led to the liquefaction of all known gases by 1898, in which year Dewar liquefied hydrogen. M. W. Travers, in 1900, made a small and simple laboratory plant for this purpose and so opened the way to the low-temperature researches which have been essential to so many of the discoveries of the last forty years.

The contribution of British men of science to the theory of the structure of solids has been fundamental. During the nineteenth century our countrymen took only a modest part in crystallography, but in 1912 came the epoch-making discoveries of W. H. and W. L. Bragg, who developed Laue's discovery, that X-rays are diffracted by crystals, into their famous method of interpreting crystal-structures by means of measurement of the intensities of X-rays reflected by crystals at different angles. Within a few years they discovered the fundamental patterns or 'lattices' that determined the form of the chief kinds of crystals, and as time went on they were able in many cases to discover the exact positions of the atoms in the molecules of chemical compounds—which the chemists had spent a century in deducing by indirect means. They showed the distinction between the structure of bodies ionised in the solid state and those not ionised; and they proved that true salts are completely ionised as solids. Their methods settled the constitution of the oxides. The fruitful conception of the *giant molecule*, the solid whose atoms are linked by chemical forces into a meshwork that continues throughout the whole mass, was a revolutionary and fruitful one. X-ray methods have proved capable of indicating to us the structure of such complex compounds as the silicates, and of many complex organic compounds such as rubber, proteins, synthetic plastics and the like. The electron-diffraction methods, developed by J. M. Robertson and others in recent years, have enabled us to make exact maps of the molecules of organic compounds and proved invaluable in discovering the structure of penicillin. Thus the study of the reflection and diffraction of X-rays and electrons by matter has not only opened up to the chemist fields formerly deemed inaccessible, but has wonderfully confirmed the notions of their structure that the chemists of the nineteenth century had deduced from their reactions and has become a valuable tool for the discovery of the structure of molecules.

The state of 'solution' has received a good deal of enlightenment from British chemists. The diffusion of dissolved substances and the phenomena of osmosis were first studied by Thomas Graham in 1850, and even earlier much attention had been given to their electrical properties. The theory of electrolysis was chiefly developed in this country. Davy's discovery of sodium and potassium in 1807 by passing an electric current through their melted compounds astonished the world, and his work gave a qualitative idea of electrolytic phenomena. Faraday in 1833-4 made the absolutely fundamental researches which led to the precise quantitative laws of electrolysis that bear his name, and this work was followed up by Daniell, who also (like Grove, Smee and others) invented a useful electrical cell. The practical side of electrolysis, namely electroplating, was developed in the years round 1840 by John Wright and the brothers Elkington.

In the great period of electrochemical research no English chemist attained the eminence of an Arrhenius, Ostwald, or Nernst, though a good deal of valuable work, especially on the hydrolysis of salts, and on conductivities, was contributed by Englishmen: in this connection the work (1910) of Harold Hartley on the conductivities of solutions other than water is particularly notable.

The chemist studies not only solids, liquids and gases, and solutions or homogeneous mixtures of these, but also the heterogeneous mixtures which are grouped under the name of colloids. The study of colloids was initiated by Thomas Graham, the first President of the Chemical Society, in the years 1861-4. Faraday had indeed investigated the brightly coloured gold sols (fine suspensions of particles of gold in water), but Graham first distinguished the class of colloids—substances which in solution diffused slowly or not at all, did not form crystals nor show the definite reactions of crystalline substances of the same chemical class. He introduced much of the terminology we still employ, including the words colloid (*kolla*, glue—the substance Graham considered to be typical of the class), *sol* and *gel*, and he discovered the process of *dialysis*, by which colloids could be purified. We have since learned that colloids are not a class of chemical substances, but rather a state which most, if not all, substances can assume. The importance of colloid studies for biology was clearly understood by Graham. In 1892-5 Harold Picton and S. E. Linder came to recognise the important phenomenon of *electrophoresis*, "the repulsion of a dissolved substance as a whole from one pole to another when we immerse, in the liquid, electrodes connected with a galvanic battery", a process which has proved to be of practical value in many industrial processes. They likewise grasped the fact that there was a continuous series of grades of solution passing from suspensions through colloidal solutions to crystallisable solutions. The theory of colloids was much further developed by F. G. Donnan and his school who originated the theoretical study of emulsions, which has now been translated into practice in numerous industries concerned with rubber, milk, lubricants, detergents and many other products.

Since 1912 extremely interesting work has been done on mono-layers. In 1912 W. B. Hardy showed that if the 'stray-field' of force from the molecules in a liquid were unsymmetrical a surface skin must be formed having all the molecules oriented in the same way. The Cambridge School under Rideal, and N. K. Adam at Southampton, have made extensive studies of surface pressure and have shown that these films can exist in states analogous to the solid, liquid and gaseous states.

The researches we have hitherto described are concerned with the *structure* of atoms, molecules, and aggregates of molecules—solids, liquids, gases, solutions, colloids; but the most characteristic part of the chemist's work is the study of *chemical change*—the recording and explanation of the manner in which compounds react to form other compounds. This again involves an enormous number of particular researches into the behaviour of every known compound, but nevertheless there are some general principles that apply to all types of chemical change. Much theoretical work has been done on the factors which will increase or decrease the numbers of contacts or collisions between molecules. The effect of concentration or dilution, high or low pressures in gases proved fairly easy to study, but the effect of temperature and of catalysts (bodies present in minute quantities, which alter the speed of reactions without themselves being changed) was a much more difficult task, by no means complete even now. The measurement of the rate at which chemical change takes place is therefore of the first importance. One of the earliest studies of the rate at which chemical reactions proceed was the researches of A. Vernon Harçourt and W. Esson in 1866, on the reaction of permanganic and oxalic acids, and Sir James Walker's studies of the rate of change of ammonium cyanate into urea (1895-1903) added greatly to our knowledge. The method used by Hartridge and Roughton (1923) for studying very rapid reactions was most ingenious. They chose two reactants which underwent a visible change on combining, and passed them at a known very high speed through two arms of a Y-shaped tube; the extent of their reaction could be estimated by the extent of visible colour change, and the time that change took by the distance along the stem of the Y at which it was apparent. A. Lapworth (1904) and K. J. P. Orton (from 1909) studied the speed of reactions of organic compounds and began the fruitful work of deducing their mechanism from their velocity, work which has since been carried much further by Robert Robinson and others. A. Lapworth, Robert Robinson and C. K. Ingold have investigated organic reactions from the point of view of ionic reaction-mechanisms, while W. A. Waters and D. H. Hey have shown that free radicles or atoms are concerned. Other workers (Polanyi, Hinshelwood) have investigated the nature and magnitude of the forces concerned.

The work of C. N. Hinshelwood, since 1922, on the rate of reaction of mixtures of gases, has been of great importance. He has established the broad validity of the collision-theory of reaction-velocity, formerly held on rather slender grounds; he has shown how the influence of molecular structure, solvent and other features on reactivity could be analysed and interpreted in terms of activation energy and probability factors.*

The phenomenon of catalysis was, from the first, extensively studied in this country. Davy in 1817 and Faraday in 1833 investigated the catalytic action of platinum. William Deacon in 1868 discovered the process of making chlorine by the reaction of hydrogen chloride and atmospheric oxygen in the presence of a catalyst; and this catalyst (a copper salt) he selected on theoretical grounds and not, as is usual, by a chance observation. The puzzling effect of intensive drying in inhibiting chemical reactions was first noticed by Mrs. Fulhame in 1794 for the case of carbon monoxide and oxygen, which react with difficulty when dry. This was rediscovered by H. B. Dixon in 1884, and H. B. Baker devoted a lifetime's work (1885-1929) to these phenomena of intensive drying, which still remain obscure. W. A. Bone, from 1902 onward, investigated the effect of surfaces in promoting the burning of hydrocarbons, and so was led to the invention of surface-combustion as a means of industrial heating. Since catalysis is of the first interest both in theory and industrial practice, great attention has been given to it in recent years. The study of the adsorption of gases by solids has proved to be fundamental to these studies.

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* See "Not too fast, not too slow" in *Science News I.*

One of the most important conceptions of chemical kinetics is the chain-reaction,* wherein the reaction of one molecule imparts to another the energy needed to cause it to react, thus giving rise to linear sequences of reacting molecules. The name of Hinshelwood may perhaps be singled out as the leader of the chief school of this type of research.

The effect of light upon chemical reactions was first studied in connection with photography. Thomas Wedgwood and Sir Humphry Davy (1802) produced images on paper treated with silver nitrate, but could not fix them. Niepce and Daguerre, on the continent, showed how to produce permanent photographs, but their methods gave only one picture, and modern photography was initiated by W. H. F. Talbot who produced the first permanent photograph on paper (fixed by concentrated sodium chloride solution). In 1839 William Herschel discovered fixation by 'hypo' and in 1841 Talbot discovered development by gallic acid. Talbot used only waxed paper negatives, but F. Scott Archer in 1846 introduced wet collodion plates, while the dry gelatine films, which have been developed into the modern type, were introduced by R. L. Maddox (1861). The work of F. Hunter and V. C. Driffield (1890) on the speed of plates is well known. Dr. S. E. Sheppard, in 1927, made the important discovery of the 'sensitising specks' on the silver bromide grains in the emulsion, which led to the possibility of producing plates of high and uniform sensitivity. Since 1920 infra-red sensitising dyes have been much developed.

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* See "Chains" in *Science News III.*

In the field of pure photochemistry, we must note the fundamental law of J. W. Draper (1841) enunciating that only light actually absorbed can produce photochemical action. Much work has been done on the effect of light upon the reaction of hydrogen and chlorine, but some obscurity still remains, after nearly a century of study: and the same may be said of the most important of all reactions, the photosynthesis of carbohydrates by plants, greatly studied by E. C. C. Baly. The chief activity in photochemistry at the present day is the study of the decomposition of organic vapours by light.

The importance of our coal, gas and metallurgical industries has prompted many of our chemists to the study of the combustion of fuel gases. Sir Humphry Davy's discovery of the safety lamp arose from his researches into flame and explosion: Faraday made further contributions. A new era began in 1880 with the work of H. B. Dixon on the rate of explosion and ignition temperatures of various explosive mixtures of gases. A Smithells showed us how to obtain specimens of gases from the interior of flames. The problem of the mechanism of combustion of hydrocarbon gases has been deeply studied by W. A. Bone and his collaborators between 1892 and 1912. H. T. Tizard and D. R. Pye in 1922 did much indeed to clear up the problem of detonation of fuel-gases in the cylinder of the internal combustion engine, but there is here still much room for investigation. The development of the theory of chain-reactions by Hinshelwood and his colleagues has, however, cleared up most of the difficulties concerning the explosion of mixtures of hydrogen and oxygen and has given us fundamental principles for the understanding of gas reactions. This will lead, we hope, to a fuller understanding of the nature of the reactions in the internal combustion engine.

The results of the investigation of natural products, the preparation of new compounds and the study of their properties has gone on continuously and the results fill thousands of volumes. We can here only note some outstanding researches or groups of researches in inorganic and organic chemistry.

British chemists have not only made important contributions to our knowledge of inorganic chemistry, but were also the founders of the heavy-chemical industry. At the beginning of the nineteenth century Davy's discovery of the alkali and alkaline-earth metals (sodium, potassium, calcium, barium, magnesium) was of fundamental importance. Among a number of nineteenth-century researches, we may note Thomas Graham's work on the arsenates and phosphates as giving us the first clear formulation of the idea of the basicity of salts. B. C. Brodie (the younger) did interesting work (1850-65) on the peroxides and on ozone and proved that the formula of the latter substance was O_3. The work of H. E. Roscoe on vanadium, at about the same period, was a classical piece of research, establishing its true valency and atomic weight, so enabling Mendeléeff to assign it to its true position in the periodic table. The discovery of thallium by Sir William Crookes and his investigation of its compounds was another fine piece of work. Crookes' researches on the rare-earths were valuable also: we have to remember also his discovery of glasses, capable of cutting off both ultra-violet and heat rays, for use by glass workers exposed to fierce heat.

Crookes also played a minor part in the greatest of

British inorganic researches, the discovery of a whole group of new elements—the inert gases, helium, argon, neon, krypton, xenon.

Lord Rayleigh had been attempting to obtain a very exact value for the density of nitrogen and in 1892 he found that the nitrogen he obtained by depriving air of all other known constituents was slightly denser than that obtained from compounds of nitrogen. In 1894 William Ramsay joined in the research and both Ramsay and Rayleigh were successful in isolating from air a new element, a gas of density 20.01, which appeared to be totally unreactive. It was named argon, and Crookes's spectroscopic examination proved it to be a new element or mixture of elements. In 1895 Ramsay obtained a gas from the mineral cleveite, and sent a specimen for spectroscopic examination to Crookes, who identified a yellow line in its spectrum with the yellow D_3 line which Frankland and Lockyer many years before had observed in the solar spectrum and had attributed to an unknown element which they called *helium*, now for the first time discovered upon earth. Ramsay and M. W. Travers then systematically searched for further inert gases, and after 1898, when Hampson's process had made liquid air available, the heavier inert gases krypton and xenon were discovered in the highest boiling fraction, and neon in the lightest. Thus in the six years 1894-1900 there were added to the periodic table five new elements, constituting a group soon to be completed by *niton* (the radioactive emanation), the determination of the atomic weight of which by Whytlaw Gray and Ramsay, using the microbalance, was a triumph of technique.

In the early twentieth century the principal field for new work was the investigation of the chemistry of the radio-elements, carried out in this country by Rutherford, Soddy and others. After the Bohr theory of the atom had thrown so much light on problems of valency inorganic chemistry was largely directed towards the study of the covalent and co-ordinated compounds of the metals, and the space-relationships of their compounds. The most recent development of all is the production of new elements and isotopes by bombardment of elements with neutrons or other particles, but this so-called *nuclear chemistry*, which culminated in the triumph of nuclear fission and the synthesis of several new elements, such as neptunium and plutonium, is really a branch of physics, though chemistry has played an indispensable part in the separation of the new elements from the parent mass.

So much for the field of pure inorganic chemistry; we must now pass to a brief survey of the British heavy-chemical industry. This industry began well before the period of modern chemistry. Ward and Roebuck founded the sulphuric acid industry in the eighteenth century: later came Hill's substitution of pyrites for sulphur, thereby further lowering the price of the acid. Charles Tennant's invention of bleaching powder increased the demand for chlorine and thereby for sulphuric acid. The Leblanc process for making soda, though first brought into use in France, was chiefly developed here, and led to the invention of several processes for disposing of its waste products. William Gossage (1835) began the conversion of the waste hydrogen chloride into hydrochloric acid and William Deacon (1868) showed how to convert it into chlorine. Very important also was Weldon's method (1868-70) of recovering the manganese used in the manufacture of chlorine. The treatment of the other by-product, alkali-waste, was made possible by A. M. Chance's process for recovering sulphur from it. Despite these improvements and economies the Leblanc process had to give way to the Solvay process, which, although a Belgian invention, was largely perfected in this country by Ludwig Mond, who in the course of these researches invented the Mond producer, and was led to the discovery of nickel carbonyl, which could be used to separate pure nickel from all other elements—so founding another industry.

Returning to the manufacture of sulphuric acid, we must note the invention of the Glover tower (1859) which further brought into practical use the Gay-Lussac towers invented in 1827. Meanwhile Peregrine Phillips in 1831 invented the 'contact' process, though it was not till 1875 that W. S. Squire and R. Messel made it capable of industrial application.

Many industries must be left almost unnoticed in a brief survey, but the work of Accum and others (*c.* 1819) on the recovery of ammonium salts from ammoniacal liquor of the gas-works was the first step towards the fertiliser industry that developed from it late in the nineteenth century. The real founder of this industry was J. B. Lawes, who invented superphosphate in 1842 and thereby again increased the demand for sulphuric acid. The Portland cement industry was also developed in this country by a number of inventors and manufacturers.

Some of our greatest discoveries have been in metallurgy, We may mention the cyanide process for separating gold, and the processes of Parkes and Pattinson for separating silver from lead. But by far the greatest were the researches that have led to improvements in the manufacture of iron and steel. Though these belong as much to engineering as to chemistry we must remember the names of Bessemer, Siemens, Gilchrist and Thomas, Hadfield, Roberts-Austen and other metallurgists as founders of our modern industrial developments.

Between 1750 and 1880 Britain was the leader in the heavy chemical industry, but in the years 1880-1914 she fell behind. In the last thirty years, however, the chemical industry has taken a fresh start and the British chemical industry is the most important in the eastern hemisphere. This defection and revival is even more noticeable in the field of organic chemistry.

Some of the earliest British work on organic chemistry was important as throwing light on the problems of valency and atomic weight. Such was the work of Williamson on the constitution of alcohol and ether, and Frankland's classical researches on the organometallic compounds. The work of Couper has already been mentioned as contributing to the idea of graphic formulæ: and the work of Alexander Crum Brown in proving the equivalence of the four valencies of carbon was an essential step towards modern organic chemistry. Kekulé's discovery of the ring-formula for benzene was made in England—on the top of a bus, we are told—and W. H. Perkin's synthesis of hexahydrobenzene from hexylene bromide and sodium was a strong piece of evidence for it.

It may be said that in the nineteenth century organic chemistry was more cultivated on the Continent than in England, though we can record a number of pieces of work, such as Frankland and Duppa's famous acetoacetic ester syntheses and W. H. Perkin's fundamental work on the aniline dyes. In late years, however, and especially since 1920 there has been a great revival of organic chemistry, so much so that the greater part of the Journal of the Chemical Society is devoted thereto. It is impossible indeed to do more than allude to some of the main trends.

On the theoretical side, the influence of groups of atoms already attached to the benzene ring upon the position of attachment of other groups added to the ring later, has been much studied in this country, *e.g.*, by H. E. Armstrong (1887) and later by Crum Brown and Gibson, whose well-known rule (1892) predicted the true results in a majority of cases. Since that time a mass of most important work concerning the mechanism of organic reactions has been done, and Lapworth, Lowry, Robinson and Ingold, between 1920 and 1926, initiated the electrochemical theory of the course of organic reactions. They envisaged a drift of electrons to one end of a molecule, caused by induction and also by another effect, the electromeric. This drift activates or deactivates the aromatic nucleus (the benzene ring), the attacking reagent seeking the point of high electron-density. The electromeric effect, mentioned above, proved to be in remarkable consonance with physical studies of resonance. This work has explained a great number of organic reactions which had never been satisfactorily accounted for. The work of Thorp and Ingold on tautomerism, of C. A. Waters and his school on free radicles, and the work of Sidgwick and his school on the apparent cases of bivalency of the carbon atom have, indeed, gone far to remove the anomalies of classical organic theory.

Much work and ingenuity and imagination have been expended on unravelling the structure of natural organic compounds. The group of *terpenes* (including many perfumes, essential oils, and also rubber) were investigated by W. H. Perkin (jun.) and by William Tilden, the first to synthesise rubber. The *alkaloids* were also investigated by Perkin, but the pre-eminent work in this field is that of Robert Robinson. The chemistry of the *carbohydrates* has been largely elucidated in this country. The work of C. F. Cross and E. J. Bevan on cellulose led to the discovery of viscose, chief source of artificial silk. T. Purdie, J. C. Irvine, W. N. Haworth and E. L. Hirst have carried on the tradition begun by the methylation technique of the first-named and have transformed this difficult branch of organic chemistry. Some progress, largely through X-ray methods, has been made towards the investigation of the *proteins*, the material of life, but there is still a great deal to be discovered in that field. The *natural colouring matters* of plants have been successfully investigated, chiefly by Robinson. The *vitamins*, of which the discovery was due in a large measure to the pioneer researches of Sir Frederick Gowland Hopkins, have received a great deal of attention. The D group of vitamins and certain of the hormones belong to the group of *steroids* which have presented particular difficulties in their investigation, largely overcome by Heilbron, and by Robinson and their schools. We may mention here the remarkable work of Harington in synthesising the active principle of the thyroid gland and the great work done at Oxford and elsewhere in the investigation and attempted syntheses of penicillin by the team of workers headed by Sir Howard Florey.

The British organic chemical industry was founded, we may think, by W. H. Perkin, who, in 1856, when only eighteen years of age, discovered the famous dye, mauve, and set up the first synthetic-dye works. In 1869 he synthesised alizarin, the active principle of madder. In the period between 1856 and 1887 British chemists and firms initiated a great number of important dyestuffs and groups of dyestuffs, but from the eighteen-eighties onward Germany captured more and more of this industry. Moreover, since the same kind of equipment and personnel is needed for the synthesis of drugs as of dyes, the new synthetic-drug industry which began in the eighties was almost entirely German. The war of 1914 gave us a rude awakening. It was necessary to build up a fine-chemical industry at short notice, and between the wars it was not allowed to lapse. Such remarkable dyestuffs as celadon jade green, phthalocyanine, and the aminoanthraquinone dyestuffs for acetate silk have been discovered and produced in this country.

The British fine-chemical industry has contributed splendidly to the conquest of disease. The production of synthetic vitamins is an example, but the greatest has been the investigation and production of the chemotherapeutic agents such as sulphapyridine, sulphathiazole, sulphadiazine and most recently penicillin. Rarely can any industry have saved so many lives.

Mention must be made of the production of plant-growth substances, selective weedkillers, and such insecticides as gammexane, which have proved invaluable in horticulture.

Finally we are to admire the new and flourishing plastic industry, first developed in the U.S.A. and on the continent, to which the research workers of Imperial Chemical Industries have made remarkable contributions, such as perspex and polythene, and further developments are to be expected.

Never, we may think, has British Chemistry, pure and applied, been in so thriving a state, and, given the means—men and material—it must prove to be among the greatest of our national assets.

GLOSSARY

AURA: The first symptoms heralding the onset of a fit, e.g., an unpleasant sensation of smell.

CRITICAL STATE: A gas or vapour can often be liquefied by compressing it; thus liquid air is made. But above a certain temperature, characteristic for each gas, this is no longer possible, and no amount of compressing will liquefy it as long as it is hotter than this critical temperature.

DETERGENT: A soap or any other substance which lowers the tension between oil and water (or any other two phases) and permits them to mix.

DIALYSIS: Sheets of material such as cellophane, or other membranes such as sausage-skin, dried pig's bladder, etc., have such very fine pores in their substance that they will let small molecules through, but offer a complete barrier to large molecules, which are too big to get through the holes. This provides a way of sorting out molecular sizes, getting the big molecules pure of the small ones. The mixed solution is placed in a closed bag of a membrane and immersed in running water; the small molecules wander out into the water and are carried away, the large ones are held behind in the bag.

ELECTRON DIFFRACTION: Although electrons are several thousand times smaller than atoms, and atoms themselves "empty space" inside, and spaced apart at regular intervals in a crystal, a beam of electrons does not pass straight through a solid and emerge unchanged the other side, but is bent and scattered in various directions in a manner reminiscent of the glistening of a spider's web in sunlight. From measurements of the intensity and direction of electron scattering, deductions can be made of the arrangement of atoms in a crystal, since the diffractions depend on the interatomic spacings.

OSMOSIS: The "attraction" into a semipermeable bag (as in Dialysis, q.v.) containing large molecules, of water or other solvent, which tries to dilute the contents to bring them to the same strength as the pure solvent outside.

PSYCHIATRY: The study of mental illness, as distinct from Psychology, which is the study of normal mental processes. Mental diseases are often divided into two groups: *neuroses*, in which the illness upsets only a part of the sufferer's life and he is aware of his abnormality; and *psychoses*, in which the illness pervades and distorts the whole personality in a way the patient is quite unaware of—what is commonly called madness or lunacy.

Psychoses may commence as the sequel to infectious disease or brain damage (from drinking too much alcohol, for example), or be completely brought on by worries and other mental or *psychogenic* causes. They are characterised by various collections of symptoms.

Hallucinations are false sense perceptions, for example hearing voices speaking in one's ear, though one is alone and in silence.

Delusions are false beliefs which cannot be shaken, no matter how much indubitable proof and demonstration to the contrary be offered.

Obsessions are ideas or delusions which take possession of the mind to the exclusion of all else—for instance, a man who imagines that he is surrounded by spies, that everyone is watching him, that every harmless passer-by is a member of the secret police.

It is difficult to discern amidst the varying combinations of symptoms that mental patients show whether there are any truly distinct diseases. However, most authorities recognise the division into schizophrenia and manic-depressive insanity, and some add further distinct varieties such as *Melancholia* (profound depression, often with delusions) and *Dementia* (progressive deterioration and loss of intellectual power—reasoning, memory, will, with insanity), which others regard only as symptoms.

Schizophrenia is characterised by a withdrawal from the real world into a dream world of one's own imagining. All emotional response to other people is lost, and the sufferer's laughter and tears relate only to events in his dream. He lapses into silence, no longer listens when spoken to, does not reply, may smile suddenly to himself, and sit for long periods staring into vacancy, apparently doing nothing. There are many forms of schizophrenia, classified according to the predominant symptom. *Catatonia* is a form in which the patient becomes melancholic and stupid, and stands for long periods motionless in one place, or will even passively hold any statuesque pose one cares to arrange him in. Schizophrenia usually gets progressively worse.

Manic-depressive insanity, on the other hand, is an illness of excessive emotion which comes in waves or cycles. Periods of extreme excitement (*mania*) alternate with periods of normality or profound depression. In other words, there is a disturbance of emotion or *affect*, and this is therefore an *affective psychosis.*

Most psychotic symptoms are only gross exaggerations of characteristics found in all normal people. The diagnosis of mental illness is a specialist's job, and this brief account is intended only as an introduction to the technical terms of the subject and may prove most misleading if used as part of a "Home Doctor".

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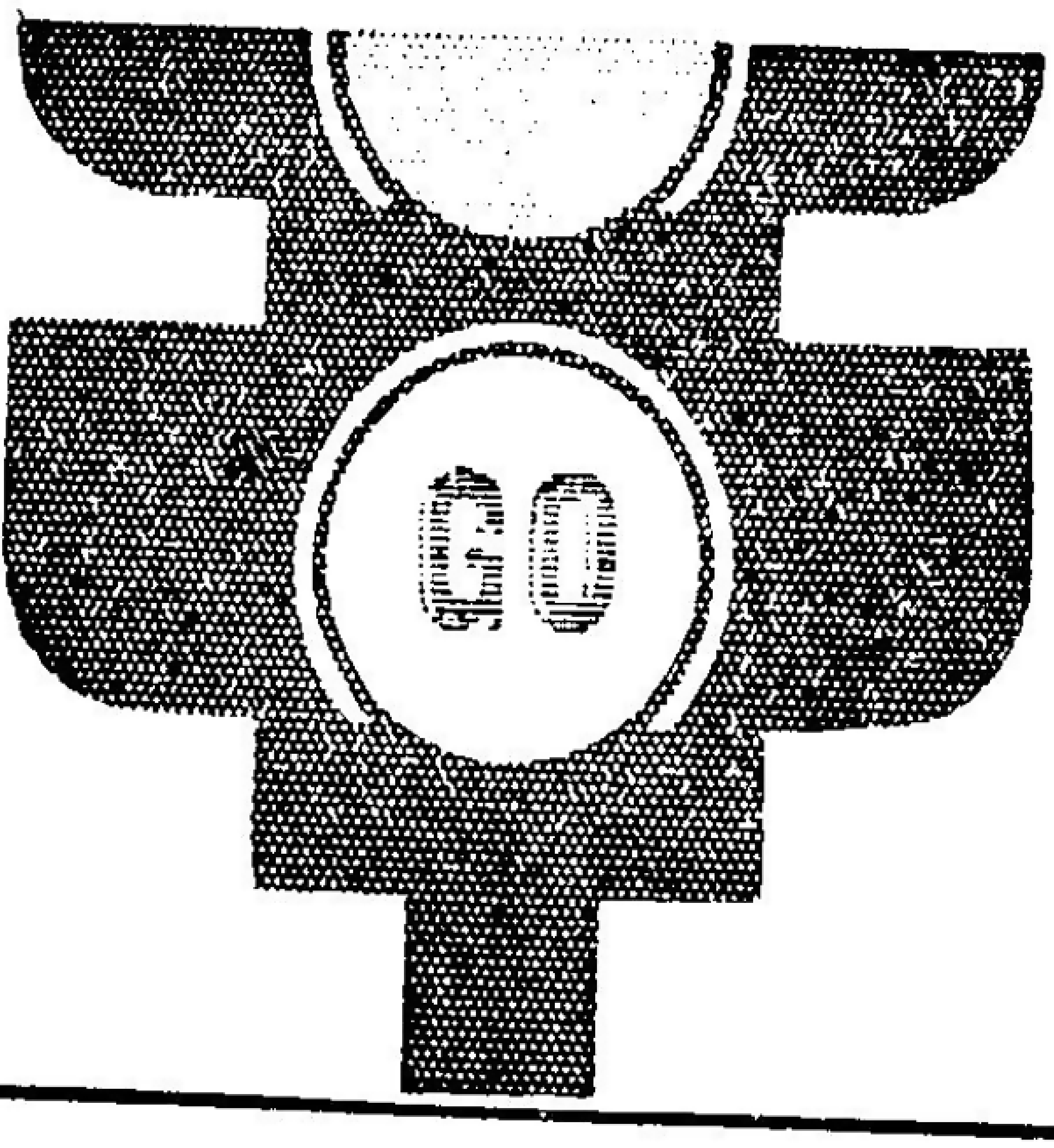

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This book is a survey of the whole field of invention, which, as everyone now realises, we must cultivate intensely or perish. We cannot earn our living, as we conceive living, by mass production of standard articles. We must earn the wages of high skill, turning a shillingsworth of raw material into a poundsworth of goods unobtainable elsewhere. All experience shows that such goods are created by individual inventors, who have found this country very unreceptive in recent times. This book is addressed to such men, to explain them to themselves and to the public at large, more particularly the manufacturers who find them difficult, and the legislators who have failed to create a patent law which ensures them a due reward under modern conditions. Nationalisation of industry creates a new and hopeful situation for the inventor, since pioneer invention, so often a dead loss for one firm after another till technical success is attained, is now a business which, if properly pursued, will benefit the industry as a whole.

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